AD-A068 019 NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA F/G 17/9
RADAR SYSTEM ANALYSIS ALGORITHMS. RADAR SYSTEM ANALYSIS MODELS --ETC(U)
OCT 78 S T LI
UNCLASSIFIED NOSC/TD-212 NL

| OF |
AD
A068019

END
DATE
FILMED
6-79
DDC

NOSC

NOSC TD 212

Technical Document 212

RADAR SYSTEM ANALYSIS ALGORITHMS

Radar System Analysis Models of Performance Degradation by Mutual Interference

ST Li

18 October 1978

Final Report: October 1976 to October 1978

Prepared for
Naval Electronic Systems Command

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

RR GAVAZZI, CAPT USN
Commander

HL BLOOD
Technical Director

ADMINISTRATIVE INFORMATION

This effort was performed at NOSC, under task area II of the NAVELEX 304 functional area funding program, System Engineering of the Electromagnetic Environment (EMX) Program. The author acknowledges, with gratitude, Dr. P. James Moser of IIT Research Institute who provided consultation support through Electromagnetic Compatibility Analysis Center (ECAC) during the fourth quarter of FY77.

Released by
LCDR S DOLLAR, Head
Communications Research
and Technology Division

Under Authority of
H SMITH, Head
Communications Systems
and Technology Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

14 NOSC/TD-212

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NOSC Technical Document 212 (TD212)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 RADAR SYSTEM ANALYSIS ALGORITHMS, Radar System Analysis Models of Performance Degradation by Mutual Interference.		~~5. TYPE OF REPORT & PERIOD COVERED~~ 9 Final Rep[redacted]t, Oct[redacted]76 – Oct[redacted]78,
		~~6. PERFORMING ORG. REPORT NUMBER~~
7. AUTHOR(s) 10 S. T. Li		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Systems Center San Diego, California 92152		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NAVELEX 304, task area II, 62762N, XF54585
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Electronic Systems Command Washington, D.C.	11	~~12. REPORT DATE~~ 18 Oct[redacted]78
		13. NUMBER OF PAGES 56
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 60p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited	16 F54585	
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Radar simulation Electromagnetic degradation Electromagnetic environments Performance degradation Radar mutual interferences		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report provides an overview of current radar system analysis models. It is an initial effort toward a radar system analysis capability as part of the Electromagnetic Environment (EMX) Program. The principles and approach of the EMX Program are outlined, existing radar system analysis models are briefly discussed, and a functional background of basic radar systems and environments is provided. The major effort is a narrative analysis of the principles and limitations of current radar analytical models and techniques. A new radar system analysis model is offered and the development of both a radar design algorithm and performance evaluation algorithm is recommended.		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

393 159

SUMMARY

OBJECTIVE

The System Engineering of the Electromagnetic Environment (EMX) Program is directed to increase the total operational performance of Navy electromagnetic systems through the reduction of electromagnetic environment degradation. Thus far, the focus of these efforts has been on communication systems. This report is the first step in implementing a radar system analysis capability: a survey of existing radar system analysis models and techniques.

RESULTS

The principles and approach of the EMX Program are outlined existing radar system analysis models are briefly discussed, and a functional background of basic radar systems and environments is provided. The major effort is a narrative analysis of the principles and limitations of the following radar analytical models and techniques:

- The ARC Shipboard Electromagnetic Compatibility Analysis Model (SEMCAM)
- The ARC Performance and Radar Degradation (PARDEG) Model, or SEMCAM 1A
- Other ARC Performance Degradation Models:
  - Delta Equivalent Noise (DEN)
  - Detection Delay Time (DDT)
  - Cumulative Reaction Evaluation Method of Active Target Environment (CREMATE)
- ECAC Signal Processing Circuit Models for:
  - On-Tune Interference
  - Adjacent Signal Interference
  - Spurious Emission
  - Spurious Response
- ECAC Performance Degradation Models/Approaches:
  - PPI Interference Prediction
  - System Performance Scoring (COSAM-type approach)
  - Performance Degradation Concepts
  - Establishment of Permissible Radar Interference Levels
- Models with Environmental Effects:
  - The NRL Surveillance Radar Systems Evaluation Model (SURSEM)
  - The NWC Search and Detection Radar System Performance Model with Environmental Effects (SADRSPMWEE)

CONCLUSIONS

The major factors that affect the prediction of radar interference and radar performance are (1) equipment, (2) operator, and (3) environments. The development of both a radar design algorithm and a radar performance evaluation algorithm is feasible. Moreover, a new radar system analysis model (figure 8) is recommended. This model incorporates both design and performance evaluation algorithms and the features of each are described.

CONTENTS

ILLUSTRATIONS

Figure

TABLES

Table

1.0 INTRODUCTION

1.1 BACKGROUND

1.1.1 EMX Program

The objective of the EMX program is to increase the total operational performance of Navy electromagnetic systems through the reduction of electromagnetic environment degradation. This is to be accomplished by the specific objective of developing a synthesis ability, which considers electromagnetic environment degradation factors during initial platform design. These degradation factors include:

- Intersystem interaction
- System site compromise
- Nonfunctional emissions

This synthetic ability would be applicable to both new ship design and fleet modernization.

The development of the synthesis requires two distinct efforts. The first effort is to structure and formulate an electromagnetic system design process that adequately considers electromagnetic environment effects (E^3). The second and primary effort is to improve and develop the analytic tools and methods essential to the implementation of EMX.

Five major task areas have been defined to encompass the approach of the EMX program. These five major task areas are:

(1) System Engineering of EMX Design Process

(2) EMX Design of Transmit and Receive Systems

(3) EMX Design of Electronic and Electrical Systems

(4) EMX Design in a Stressed Environment

(5) Radiation Hazard Criteria for EMX Design

The first major task area is concerned with the formulation and structuring of the EMX design process. The other four task areas consider the improvement or development of the tools and methods essential to the EMX design process. The second and third task areas consider designs of transmit/reception systems and electrical/electronic systems respectively. These task areas are constrained to considerations of the nonstressed envrionment. The fifth task area develops EMX design criteria for chemicals (fuel) and personnel. Again, only a nonstressed environment is considered. Finally, in area four, EMX design is developed in a stressed environment.

1.1.2 Transmit and Receive System Tools and Techniques

The basic philosophy of EMX states that electromagnetic systems must be conceived, designed, integrated, and used with utmost concern for how they support the operational requirements of the platform. The ability to convert technical parameters into performance parameters understandable by ship design, operations, and platform acquisition managers is one of the primary thrusts of the EMX design process. Thus, the objective of this task area is to develop tools and techniques that provide a design capability which relates a design to performance.

Most of the endeavor to date has related to communication transmit and receive systems. A communication system analysis capability (DECAL/PECAL) is being developed (ref 1, 2). The next effort in this task area is the implementation of a radar system analysis capability. This report is the first step in this effort–a survey of existing radar system analysis techniques.

1.2 EXISTING RADAR SYSTEM ANALYSIS MODELS

Modeling techniques implemented by digital computers are becoming recognized as the most cost-effective approach for radar system analysis. For example, the Shipboard Electromagnetic Compatibility Analysis-Microwave portion (SEMCAM) (ref 3) and Platform Analysis Routine with Degradation (PARDEG) (refs 4, 5) are two computer programs developed by Atlantic Research Corporation (ARC) for the Naval Ship Engineering Center (NAVSEC) for the purpose of predicting potential mutual radar interference aboard naval ships. In an electronically congested area such as naval ships, the mutual interference between co-site radars can be severe enough to seriously degrade their utility. SEMCAM and PARDEG are the computer programs which directly address the shipboard radar interference prediction problem. Other computer programs such as Surveillance Radar Systems Evaluation Model (SURSEM) developed by the Naval Research Laboratory (NRL) (ref 6) and Search and Detection Radar System Performance Model with Environmental Effects (SADRSPMWEE) developed by the Naval Weapons Center (NWC) (refs 7, 8) address more the effects of sea clutter, wind, rain, multipath, and atmospheric refraction on the detection capability of a radar, than the problem of prediction of mutual radar interference.

Atlantic Research Corporation and Electromagnetic Compatibility Analysis Center (ECAC) have made continuous efforts to develop a more realistic radar system analysis model which addresses mutual interference problems. In general, the function of a radar receiver can be divided into two parts: one is in the area of signal processing and the other is

---

1. Rockway JW, Li ST, Baran DE and Kowalyshyn W, Design Communication Algorithm (DECAL), paper presented at IEEE 1978 International Symposium on Electromagnetic Compatibility, in Atlanta, Georgia, 20-22 June 1978.
2. Minor LC, Koziuk FM, Rockway JW, and Li ST, PECAL – A new Computer Program for the EMC Performance Evaluation of Communication Systems in a Cosite Configuration, paper presented at IEEE 1978 International Symposium on Electromagnetic Compatibility, in Atlanta, Georgia, 20-22 June 1978.
3. Atlantic Research Corporation, NAVSEC SEMCA Computer Program User's Guide, prepared for Naval Ship Engineering Center, 29 May 1975.
4. Butturff HP, et al, Degradation of Search Radar PPI Reference in an Electromagnetic Environment, Atlantic Research Corporation, final engineering report 53-5588 prepared for Naval Ship Engineering Center, under contract no. N0024-73-C-1214, December 1974.
5. Atlantic Research Corporation, EM Degradation Feasibility Study, prepared for Naval Ship Engineering Center, under contract no N00024-73-C-1214, August 1973.
6. Kaplan DJ, Grindlay A, and Davis L, Surveillance Radar Systems Evaluation Model (SURSEM) Handbook, NRL Report 8037, 14 January 1977.
7. Cornette WM, Search and Detection Radar System Performance Model with Environmental Effects: User's Manual and Program Listing, NWC Technical Memorandum 3150, April 1977.
8. Cornette WM, and Shlanta A, Radar System Performance Modeling with Environmental Effects (Preliminary Report), Volume 1, Theory, NWC Technical Memorandum 2698, Volume 1, February 1976.

in the area of information extraction. As far as mutual radar interference is concerned, the first area is in the study of receiver processing effects on the interference; the second area is in the study of the processed interference effects on receiver performance. This report will present the efforts of ARC and ECAC in these two areas.

Computer programs such as Interference Prediction Model (IPM) developed by Litton and Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP) developed by McDonnell Aircraft Company are used to predict potential interferences involving communication as well as radar systems. These two programs have been described (ref 9) and, therefore, will not be presented again in this report.

Section 2.0 describes radar systems briefly. Sections 3.0 and 4.0 discuss two existing modeling techniques – SEMCAM and PARDEG. PARDEG extends the capability of SEMCAM to include signal processing circuit models which were developed by ARC. Section 5.0 presents the efforts of ARC in the development of performance degradation models. Sections 6.0 and 7.0 describe the efforts of ECAC in the development of signal processing circuit models and performance degradation models. Section 8.0 discusses models with environmental effects which were developed by NRL and NWC. Section 9.0 presents conclusions and recommendations for the development of a design algorithm and a performance evaluation algorithm for radar systems.

---

9. NELC TD 506 (NOSC), Electromagnetic System Integration Algorithms, ST Li, unclassified, January 1977.

2.0 INTRODUCTION TO RADAR SYSTEMS

2.1 DESCRIPTION OF A RADAR SYSTEM

Radar is an electromagnetic device for the detection and location of objects. A fundamental concept behind radar is the fact that electromagnetic waves can propagate through atmosphere in a calculable manner, at a known speed. Furthermore, any obstructions or changes in a propagation path will give rise to echoes that can then be detected. Thus, it provides information as to the presence and properties of such obstructions or changes. This radar principle has been applied with frequencies of a few megahertz to 70 GHz. The commonly used letter designations of radar frequency bands are indicated in table 1.

The particular techniques for implementing the radar concept differ markedly over this wide range of frequencies, but the basic principles remain the same.

Figure 1 illustrates the block diagram of one form of simple radar. The radar signal, usually in the form of a repetitive train of short pulses, is generated by a transmitter and radiated into space by an antenna. A common antenna is usually used for both transmitting and receiving. A fast-acting switch called the transmit-receive (TR) switch disconnects the receiver during transmission for the purpose of protecting the receiver from damage by the high-power transmitted signal. After passage of the transmitted signal, the TR switch reconnects the receiver to the antenna.

Obstructions, or targets, intercept and reradiate a portion of the radar signal. A small amount of the returned signal, or echo, is collected by the antenna. The anti-transmit-receiver (ATR) switch, which has no effect during the transmission portion of the cycle, acts on reception to channel the received signal power into the receiver.

The receiver is generally of the superheterodyne type. The RF amplifier shown as the first stage of the superheterodyne might be a low-noise parametric amplifier, a traveling-wave tube, or a maser. Many microwave radar receivers do not have an RF amplifier and use

Table 1. Radar Frequency Band

Radar Frequency Band	Frequency
HF	3-30 MHz
VHF	30-300 MHz
UHF	300-1,000 MHz
L	1,000-2,000 MHz
S	2,000-4,000 MHz
C	4,000-8,000 MHz
X	8,000-12,500 MHz
K_u	12.5-18 GHz
K	18-26.5 GHz
K_a	26.5-40 GHz
Millimetre	>40 GHz

the mixer as the first stage, or front end. The mixer and local oscillator (LO) convert the rf signal to an intermediate frequency (IF), since it is easier to build high-gain narrowband amplifiers at the lower frequencies. A typical IF amplifier might have a center frequency of 30 or 60 MHz and a bandwidth of 1 or 2 MHz.

The matched filter is designed to maximize the output signal-to-noise ratio and is sometimes classified as a signal processor. Another example of a signal processor is the delay-line canceler of the MTI (moving target indication) radar. The signal processor may be either before or after the second detector. The data processor is usually a digital device. In the past the signal processor has generally been analog, but with advances in digital techniques, this distinction is disappearing.

The RF pulse modulation is extracted by the detector and amplified by the video amplifier to a level where it can operate the indicator, usually a cathode-ray tube (CRT). There are various display techniques which enable an operator to observe the presence, location, and size of targets. For example, a plan position indicator (PPI) maps the target in angle and range on a polar display. Target amplitude is used to modulate the electron beam intensity as the electron beam is made to sweep outward from the center with range. The beam rotates an angle in response to the antenna position. For search radars PPI effectively provides a picture of the target environment.

The target location variable can be caused to generate control voltages to position the antenna (tracking radar application), to aid in the aiming and firing of suitable weapons; or, by use of a communication link, to control the flight of a missile. In some of the more advanced applications the data from the radar are stored in suitable form for later processing by a computer. Figure 2 shows a block diagram of a modern radar system.

The block diagrams of figure 1 and figure 2 are only two versions of many variations of radar systems. Furthermore, the diagrams are by no means complete since they do not include many devices normally found in most radars. Additional devices might include a means for automatically compensating the receiver for changes in radar gain (AGC), frequency (AFC), receiver circuits for reducing interfering or unwanted signals, circuitry for discriminating between moving targets and stationary objects (MTI), etc.

2.2 NOISE, CLUTTER, AND INTERFERENCE

There are two basic operations performed by radar, (1) detection of the presence of reflecting objects, and (2) extraction of information from the received waveform to obtain such target data as position, velocity, size, shape, change of shape, and angular direction. However, the operations of detection and extraction must be performed in the presence of noise and clutter echoes, and sometimes in the presence of interferences from co-site transmitters, and/or deliberate interferences from a hostile environment. This section briefly describes noise, clutter, and interferences.

Noise ultimately limits the capability of any radar. External noise enters the receiver via the antenna terminals along with the desired signal. Internal noise is generated within the receiver itself. At microwave frequencies (300 MHz through 300 GHz), the external noise level is relatively low and the sensitivity of conventional radar receivers is determined primarily by internal or system noise. However, microwave receivers with low-noise input stages such as masers and parametric amplifiers are more likely to be limited by external noise. Low-noise receivers are usually operated at frequencies from about 1.0 GHz to 10.0 GHz.

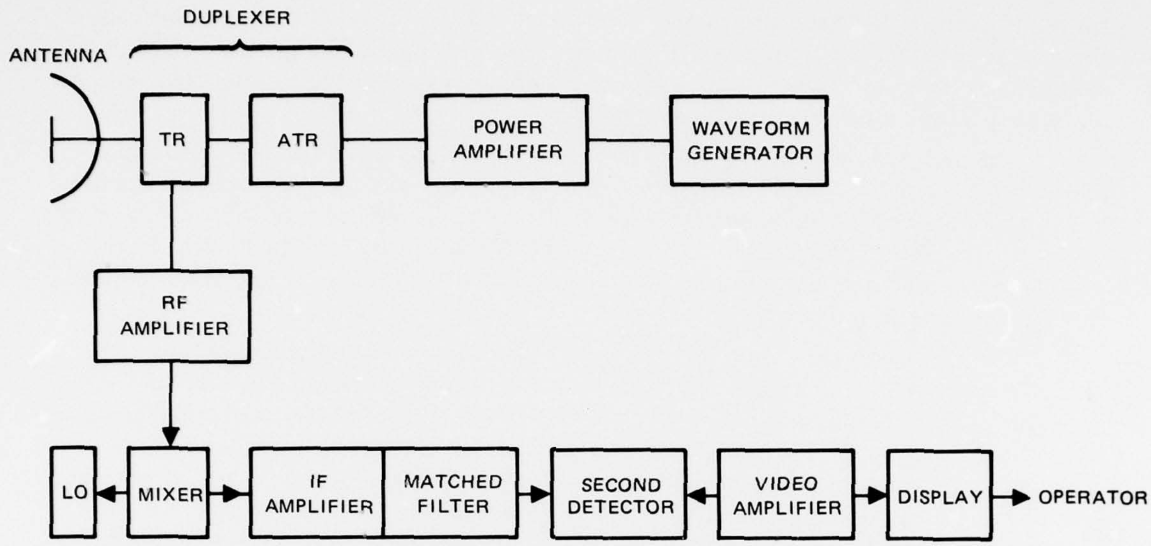

Figure 1. Block diagram of a radar employing a power-amplifier transmitter and a superheterodyne receiver.

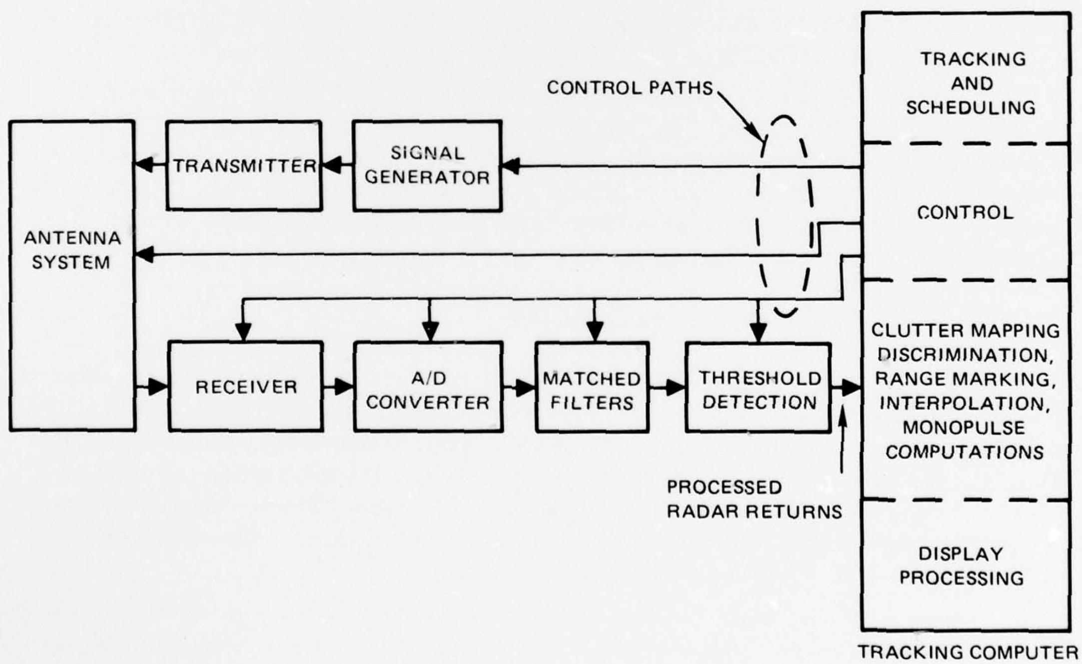

Figure 2. Block diagram of a modern radar system.

The various sources of external noise are cosmic noise, atmospheric absorption noise, atmospheric noise that arises from lightning-stroke radiation, etc. In general, cosmic noise is of considerable importance in the design of radars which operate in the VHF or the UHF bands, but it may usually be neglected at L-band frequencies or higher. At the higher frequencies (X-band or above) atmospheric absorption is the predominant contributor to the external noise. Atmospheric noise is seldom an important consideration in radar design except for radars in the lower VHF region (below 50 MHz). Although noise can never be completely eliminated, it may be minimized by designing the receiver as a matched filter or as a cross-correlator.

Clutter is defined as a conglomeration of undesired radar echoes. To a radar search for aircraft targets, clutter echoes include reflections from trees, vegetation, hills, man-made structures, and the surface of the sea. Reflection from storm clouds, precipitation, and other meteorological phenomena which confuse the radar display may also be considered as clutter. Radar echoes can be obtained from regions of the atmosphere where no apparent reflecting source exist. These have been called "angels". Angel echoes have been attributed to various causes, including birds, insects, and meteorological effects. The main difference between clutter and noise is that some correlation often exists between successive radar echoes from clutter, but noise is usually completely independent from pulse to pulse.

Interferences radiated by co-site radar, communications, or countermeasure transmitters differ in character from clutter echoes, but may be severe enough to seriously degrade radar performance. The interfering signals might be pulsed, cw, or modulated cw. In this report the emphasis will be on pulse interference.

Usually, the interfering signal from co-site radar consists of a train of radio frequency (rf) pulses whose pulse repetition frequency (prf) may, or may not, be constant; and whose carrier frequency may, or may not, correspond to that of the desired signal. In general, the prf of the interfering signals will not be the same as that of the victim radar; even if it were the same, they probably would not be synchronized. Therefore, interfering pulses usually will not appear on a radar display at the same range on each sweep.

A military radar operating in a hostile environment may be subjected to deliberate interference which appears as extraneous responses on the radar display. The various techniques that electronically interfere with radar performance are called electronic countermeasures (ECM). ECM can be classified as confusion or deception countermeasures. The purpose of a confusion countermeasure is to mask targets by cluttering the radar display. Its effects are similar to ground or sea clutter except that confusion ECM usually covers more area on the radar display than clutter does. The purpose of a deception countermeasure is to present false signals to the radar which appear as though they were echoes from real targets. If a sufficiently large number of false targets were to appear on the radar display, the operator might not be able to process them all. Some real targets might be lost, or else the radar operator might direct a weapon to a nonexistent target.

2.3 NOISE, CLUTTER, AND INTERFERENCE REDUCTION TECHNIQUES

Techniques and devices for improving the detection of desired targets from noise, clutter, and interference are discussed in this section.

2.3.1 Noise Reduction

The ability of a radar receiver to detect the desired signal and extract information from it is limited by the presence of noise. Although noise can never be completely eliminated, it must be minimized. The signal-to-noise ratio may be maximized by designing the receiver as a matched filter or as a cross correlator. The matched filter is an optimum method for the detection of signal in noise.

2.3.2 Clutter Reduction

Devices for reducing the effects of clutter echoes are the moving target indicator (MTI), the matched clutter-rejection filter, the sensitivity time control (STC), and the logarithmic receiver, etc. The basic desire in designing a radar to detect targets in clutter is to increase the ratio of target-signal to clutter-signal. The MTI and matched clutter-rejection filter can increase this ratio. On the other hand, the STC and logarithmic receiver are designed to prevent saturation of the receiver or the display.

2.3.3 Interference Reduction

Interferences radiated by co-site radar may be reduced, to some extent, by operating nearby equipments on different frequencies. In practice, however, the frequency spectrum of the transmitted waveform (from a particular equipment) can extend well beyond its receiver bandwidth. Considerable interference energy might appear at other co-site radar receivers, even though large frequency separations are maintained among co-site radars. The rectangular pulse produces a relatively large amount of interfering energy at adjacent frequencies as shown in figure 3. On the other hand, the gaussian-shaped pulse produces a

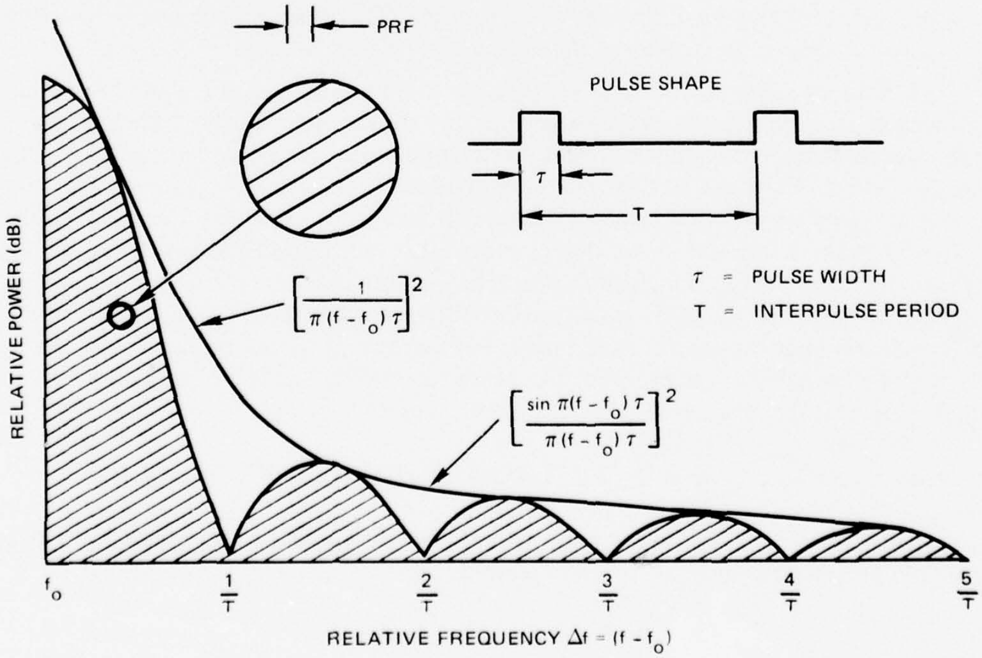

Figure 3. Rectangular-pulse spectrum.

spectrum which decreases rapidly with frequency. A gaussian pulse would be preferred when it was necessary to minimize interference. Unfortunately, a gaussian-shaped pulse is not a desirable radar waveform, since the combined accuracy with which range and doppler velocity can be simultaneously measured is poor. Pure rectangular pulses and gaussian-shaped pulses are not realized in practice. However, their spectra are indicative of the limits that might be expected with practical radar waveforms.

Other frequency components exist in the transmitted spectrum besides those predicted by the Fourier transform of time waveform. These are spurious emissions. The development of cw drive-signals from a stable low-frequency source is an increasingly popular scheme. Unfortunately, at each stage of multiplication, undesired sidebands are generated which continue through the drive chain and appear as part of the composite spectral output. Minimizing such spurious outputs becomes necessary where many similar systems are to be used simultaneously in a small co-site area. Filtering at the lowest possible power level after multiplication is essential to avoid this type of problem.

A variety of devices have been developed to minimize the effect of radar interference. These are the filter, sector blanking, pulse blanker, pulse-repetition-frequency (prf) discriminator, pulse-width discriminator, sidelobe reduction, sidelobe blanking and pulse synchronization. Most devices and techniques for the reduction of clutter echoes may be used to reduce interferences. In addition, an experienced operator is important in detecting targets in the presence of undesired interference and clutter echoes on a radar display.

Section 2.0 has described radar systems briefly. For more extensive discussions on this subject, see references 10 and 11.

---

10. Skolnik MI, Radar Handbook, McGraw-Hill Book Company, New York, 1970.
11. Skolnik MI, Introduction to Radar Systems, McGraw-Hill Book Company, New York, 1962.

3.0 SEMCAM

SEMCAM was developed by Atlantic Research Corporation (ARC) for the Naval Ship Engineering Center (NAVSEC) (ref 3). SEMCAM is the microwave portion of the SEMCA (Shipboard Electromagnetic Compatibility Analysis) computer program for the purpose of predicting potential mutual radar interference aboard Naval ships. SEMCAM has also been called Platform Analysis Routine (PAR), or SEMCAM I.

3.1 MODELING APPROACH

Figure 4 shows the block diagram of SEMCAM. The transmitter power output is represented by a transmitter emission spectrum. The transmitted signal is then attenuated by the coupling loss between the transmitting and receiving antenna terminals. A radar receiver is modeled by receiver noise figure, rf bandwidth and selectivity, and IF bandwidth and selectivity. All amplifier gains and loss factors of the receiver are assumed to be zero. The transmitter-receiver frequency separation determines which emission spectrum lobes will be passed by the receiver. The SEMCAM program determines the burn-out power at the receiver front-end and the theoretical interference-to-noise ratio (INR) at the final IF output.

3.2 INTERFERENCE THRESHOLD CRITERIA

SEMCAM calculates INR at the final IF output. INR is defined as the ratio of the peak received interfering signal power to the receiver thermal noise power, calculated at the final IF output. The INR threshold criterion is zero dB. This criterion means that if an interfering signal power level exceeds receiver noise, SEMCAM predicts the existence of mutual radar interference.

In addition, SEMCAM calculates the burn-out power which is defined as the peak interfering signal power at the rf filter output. The threshold criteria for burn-out power levels are set by users as input data; one for pulse interfering signal, the other for cw interfering signal. These burn-out level criteria can be obtained through specification, measurement, or nominal data. If no entries are made, zero dB/m are assumed by the SEMCAM program.

Equations for the calculation of INR and burn-out level are not given in the User's Guide (ref 9).

3.3 OTHER NOISE AND INTERFERENCE

SEMCAM considers only receiver noise. It does not consider external noise and clutter echoes.

Interference and receiver burn-out caused by fundamental power and harmonics are considered in the SEMCAM program. Interference due to spurious emissions is not considered.

3.4 ATTENUATION AND ANTENNA COUPLING MODEL

RF energy is guided from the transmitter through various components to the antenna, or from the antenna through other components to the receiver, by means of transmission lines. The types of transmission lines most often used in conventional radar systems are enclosed waveguides, coaxial lines and striplines. The transmission lines may be employed as

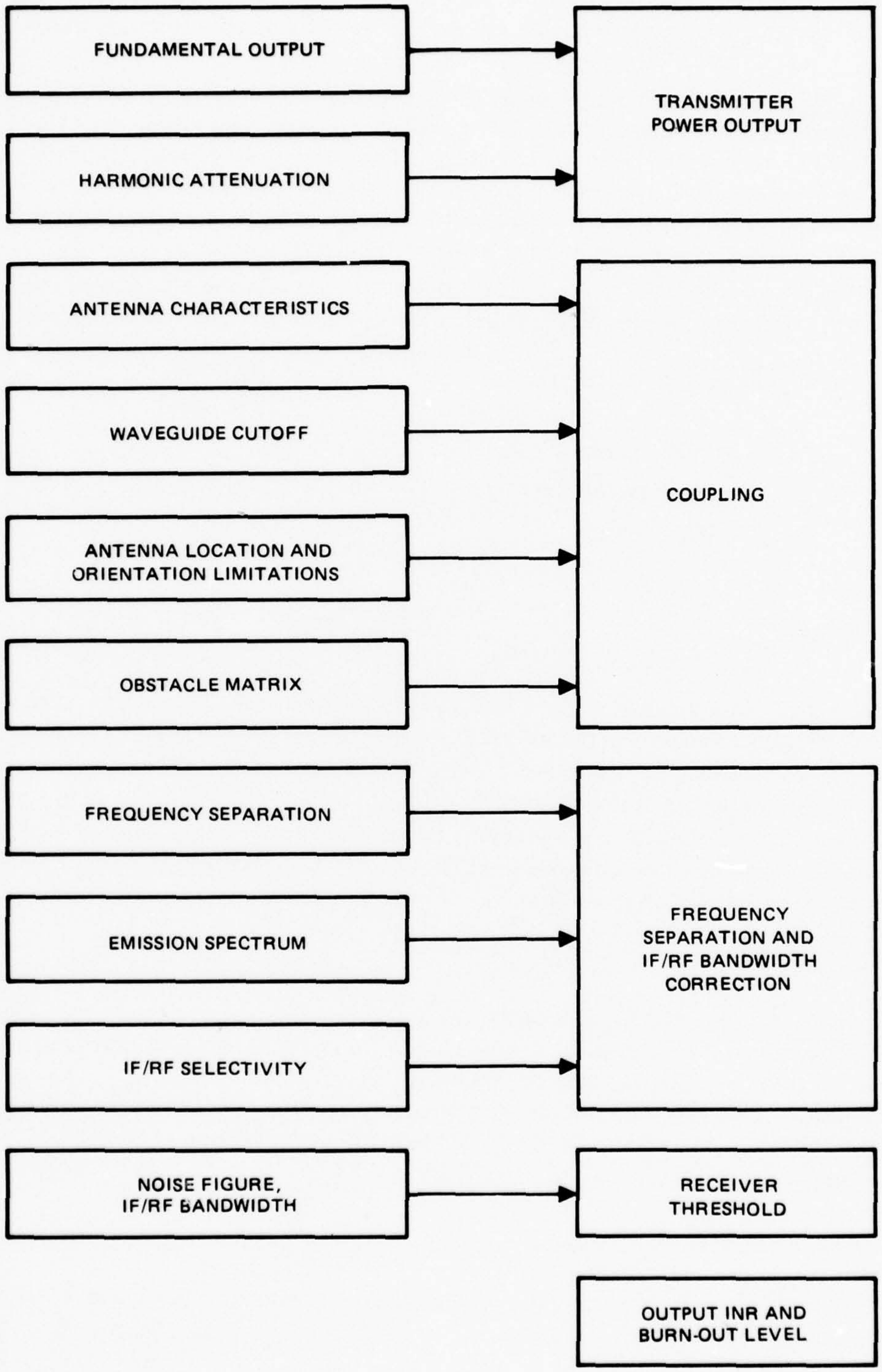

Figure 4. Functional block diagram for SEMCAM.

resonant circuits, impedance matching or measuring devices, or as the basic structures of the various components. It seems that SEMCAM does not simulate the effects of transmission lines.

In the SEMCAM program, waveguide cutoff frequency is not directly used in the calculation of INR and burn-out level, but is used as a reference frequency for certain checks made after the calculation. For example, if the RF interference frequency is below waveguide cutoff frequency of transmitter or receiver, a symbol (ϵ) is printed alongside the calculated INR and burn-out level. Therefore, it seems that SEMCAM does not account for any attenuations due to a waveguide operating below its cut-off frequency.

The antenna coupling subroutine of SEMCAM considers the effect of obstacles between each transmitter-receiver antenna pair. The obstacles are classified as follows:

Obstacle classification	Blockage
· None	$\theta < 0.01$
· small obstacle	$0.01 < \theta < 0.5$
· medium obstacle	$0.5 < \theta < 1.0$
· large obstacle	$1.0 < \theta$

where

$$\theta = \frac{A}{r^2} \; ,$$

θ is the angular blockage in steradians, A is the surface area of the object normal to the two antennas, in square metres; r is the distance between the antenna (transmitting or receiving) and the obstacle in metres. The above θ is the average value of that calculated separately for the transmitting and receiving antennas.

Antenna coupling data, or equations for the calculation of the antenna coupling for each obstacle classification, are supplied by SEMCAM. Antenna coupling algorithms are not described in the User's Guide (ref 3).

3.5 FLEXIBILITY

There are two modes available for the simulation of a radar system: the worst case and the best case. The worst case uses the set of equipment characteristics that will, in general, produce worst-case results such as using highest transmitting peak power, shortest pulse width, highest PRF and the widest receiving system bandwidth. Conversely, the best-case uses the set of equipment characteristics that will produce best-case results.

The program may be run as a batch job or from a remote terminal.

3.6 DATA BASE REQUIREMENTS

The transmitter, receiver, and antenna data are obtained from measurement, specifications, or nominal data. They are stored on the COMRADE Data Management System (CDMS) data base.

Data for both worst-case and best case are required. The data include:

Transmitter: (1) peak power in dB/m

(2) pulse width in μsec

(3) pulse repetition frequency (prf) in pps

(4) pulse compression (P.C.) ratio

(5) tuning range in MHz

(6) emission spectrum (If user supplied data are not available, program supplied models will be used)

(7) harmonic table (mean and standard deviation)

Note that spurious emissions are not considered.

Antenna: (1) location of system antenna

(2) antenna scan limits

(3) operating frequency range

(4) main beam gain in dB

(5) polarization

(6) horizontal and vertical beamwidth in degree

(7) aperture dimension in feet

(8) waveguide cutoff frequency in MHz

(9) sidelobe gain factor in dB

(10) scans per minute

Receiver: (1) RF tunable or not

(2) tuning range

(3) burn-out level, pulse in dB/m

(4) burn-out level, CW in dB/m

(5) IF frequency in MHz

(6) image rejection in dB

(7) noise figure in dB

(8) minimum visible signal (MVS) sensitivity in dB
For most radars, MVS corresponds to a signal-to-noise ratio of -8 dB.

(9) RF selectivity

(10) IF selectivity

3.7 OUTPUT

SEMCAM provides two forms of outputs, namely, detailed output and summary output.

For each transmitter and receiver pair, the detailed output gives the following items:

(1) INR (mean value and standard deviation),

(2) maximum INR above waveguide cutoff,

(3) interference false alarm rate (IFAR) at 0.5 confidence level,

(4) probability of INR exceeding zero dB at 0.5 confidence level,

(5) frequency difference required for no interference at the 0.99, 0.9, and 0.5 confidence levels,

(6) antenna coupling,

(7) burn-out power level (mean value and standard deviation),

(8) maximum power above waveguide cutoff,

(9) frequency separation required to avoid burn-out at the 0.99, 0.9, and 0.5 confidence levels.

Most of these items give values for various conditions, such as:

a. Whether it is for fundamental or harmonic emission,

b. Whether it is for maximum or minimum frequency separation,

c. Whether it is for worst-case or best-case, and

d. Whether it is for transmitter mainbeam to receiver mainbeam (MM) or transmitter mainbeam to receiver sidelobe (MS), or transmitter sidelobe to receiver mainbeam (SM), or transmitter sidelobe to receiver sidelobe (SS) antenna coupling.

For each transmitter and receiver pair, the summary output gives INR and burn-out levels. These values are the maximum values and the most probable values of various transmitting antenna to receiving antenna coupling situations (mainbeam to mainbeam, mainbeam to sidelobe, sidelobe to mainbeam, and sidelobe to sidelobe).

3.8 COMMENTS ON SEMCAM

SEMCAM simulates a radar system in a simple way. It can be used as a design tool in the early stages of shipboard radar system design. However, it cannot predict radar system performance degradation, caused by local interferences, necessary for a final system design. SEMCAM shortcomings are listed as follows:

1. For a radar receiver, a variety of hardware devices have been developed to minimize the effects of radar interference, jamming, and clutter. SEMCAM considers only the rf and IF selectivities of a receiver. A more realistic radar system analysis model should simulate the effects of these interference reduction devices and the functional blocks beyond the last IF stage.

2. SEMCAM uses receiver noise as an interference threshold criterion. The effects of interferences on radar system performance are not considered. To develop a more realistic radar system analysis model, the following questions should be answered:

a. What are the radar system performance parameters?

b. Is INR the only factor that affects radar system performance parameters?

c. What are the factors that affect the ability of a human operator (or automatic signal processor) to detect and to track targets?

d. What interference level should be used as threshold criteria? and where in the receiving system should these interference criteria be applied?

3. SEMCAM considers only receiver internal noise. A more realistic radar system analysis model should consider the effects of external noise and clutter as well as receiver noise. In addition, interference due to transmitter spurious emissions should be considered.

4. SEMCAM calculates receiver burn-out level without considering amplifier gains. In reality, automatic gain control (AGC) of a receiver should be considered in calculating burn-out levels.

5. The effects of transmission lines (enclosed waveguides, coaxial lines, and striplines) should be considered in a radar system analysis model, if SEMCAM does not do so. It would be better that SEMCAM accounts for the attenuations due to a waveguide operating below its cutoff frequency.

6. It seems possible to improve the antenna to antenna coupling models used in SEMCAM. An antenna-to-antenna coupling model which considers the effects of obstacles between antennas should be developed. This model may be run off-line if necessary.

4.0 PARDEG

4.1 BACKGROUND

Since the completion of the SEMCAM program, ARC has made several efforts to improve it. SEMCAM predicts INR at the receiver IF output. A goal was set to extend the interference prediction at IF output to a performance degradation measure; e.g., reduction in range capability for a given probability of detection. In the transition between IF output levels and measure of performance degradation, there are two general classes of circuitry encountered: signal processing and information extraction. Therefore, the goal of ARC was to extend the capability of SEMCAM to:

- include signal processing effects on both desired signals and interference signals, and
- provide measures of performance degradation, resulting from the presence of interference at the information extraction system, such as the PPI display and its operator.

The first extension is actually a refinement to the existing SEMCAM program, while the second provides the EMC engineer with an interpretation of the INR numbers. This section describes the result of the first extension: a computer program called PARDEG (also called SEMCAM 1A). Section 5.0 presents the results of the second extension: measures of performance degradation.

4.2 PROGRAM DESCRIPTION:

PARDEG is an improved version of SEMCAM which is used to predict potential mutual radar interference aboard Naval ships (refs 4, 5). Models of filters, detectors and signal processing circuits are included in the PARDEG program. Figure 5 shows the block diagram of PARDEG. Functionally, the PARDEG program consists of an executive routine and a large number of subroutines. The executive routine generates the transmitter-receiver pairs and then sequences the interference signal through each of the processing model subroutine identified by the input. PARDEG can be used to determine the INR at receiver IF output, with nearly identical results as SEMCAM, or to determine the INR at the radar video output including the effects of all receiver processing circuits. In general, the PARDEG program considers each transmitter-receiver pair aboard a Naval ship and calculates the peak received rf interference power as well as the INR and pulse width at any user-designated point in the receiver circuitry.

Input data required by the program include both data stored in the data base (permanent file) and user input data. The stored data include measured or nominal characteristics of most transmitter, receiver, and antenna systems used on Naval ships. User input data are entered in two steps. First, data to specify the equipment and the antenna locations and orientations in the run are entered and stored in a computer file (file 14) by a preliminary program designated as PROBIN. Secondly, additional user data as well as the characteristic and location files are then read into the PARDEG program. These additional user data include identification of the processing circuits used on each receiver as well as the proper sequence and the necessary parameters which characterize the circuits.

Signal processing circuits are used to reduce the effects of noise, clutter and interferences. These circuits include those which regulate signal or noise amplitudes, those which discriminate (based on time or frequency characteristics), and those which allow for self-cancellation of unwanted signals. Signal processing can be classified as radio frequency (RF)

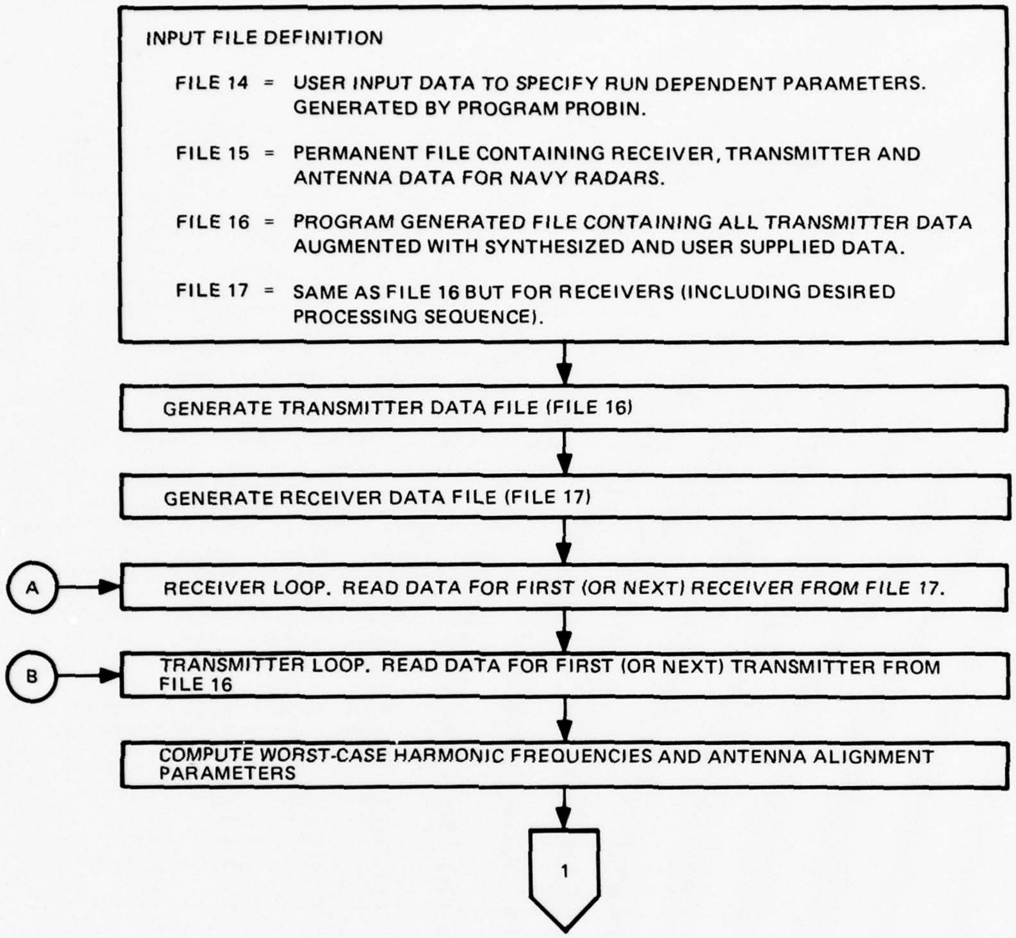

Figure 5. Functional flow diagram for PARDEG.

processing, intermediate frequency (IF) processing, and video processing. Table 2 lists these receiver signal processors.

4.3 COMMENTS ON PARDEG

PARDEG is an improved version of SEMCAM. Some of the shortcomings of the SEMCAM program indicated in Section 3.8 do not exist in the PARDEG program. The program consists of a large number of signal processing models which simulate the effects of interference reduction devices at rf, IF, and video stages of a receiver. Therefore, the shortcomings 1, 4, and 5 as listed in Section 3.8 can be eliminated. However, the shortcomings concerning interference threshold criteria, performance degradation, external noise, and antenna coupling models are yet to be resolved.

The next section describes ARC's effort in the development of performance degradation models.

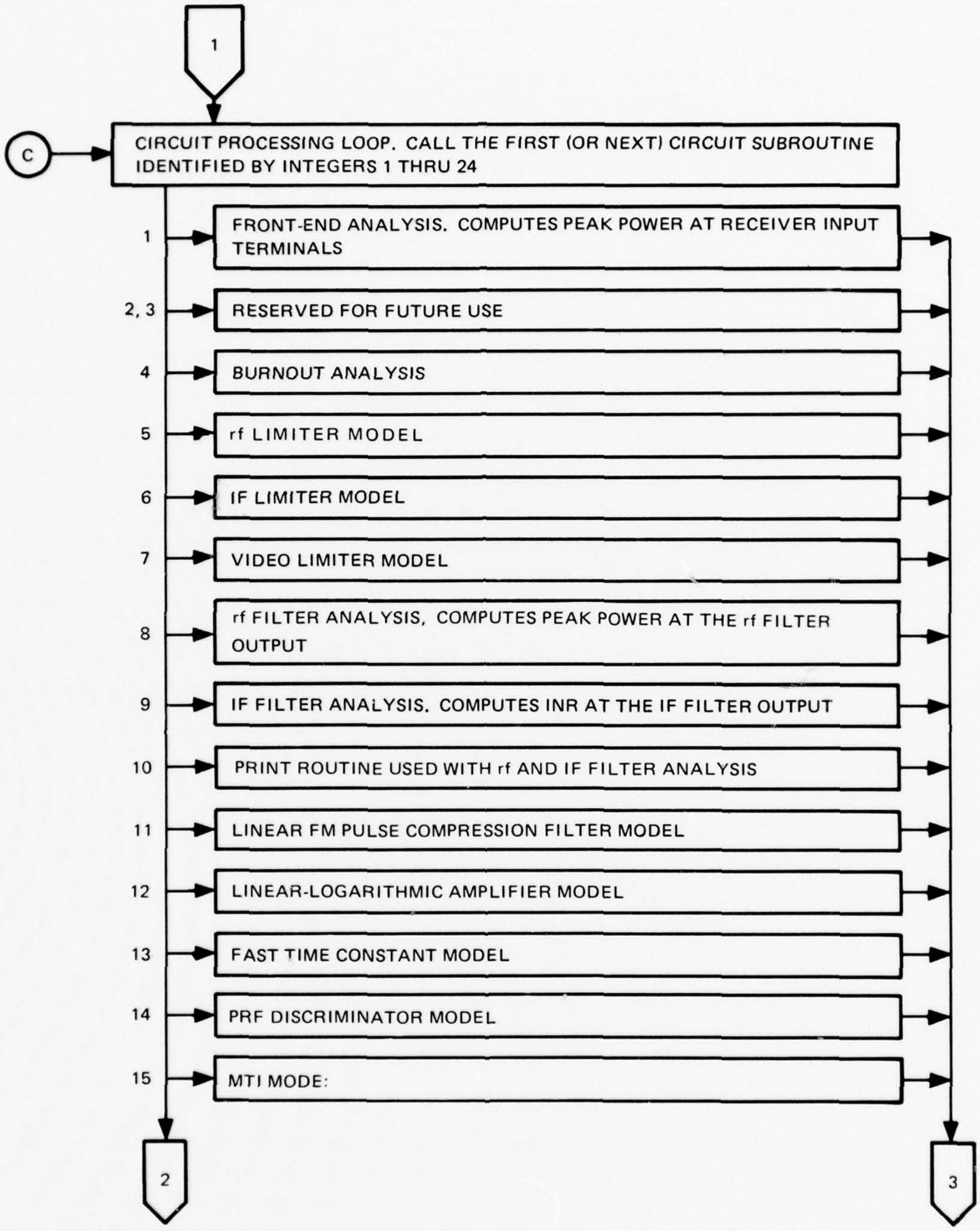

Figure 5. (Continued).

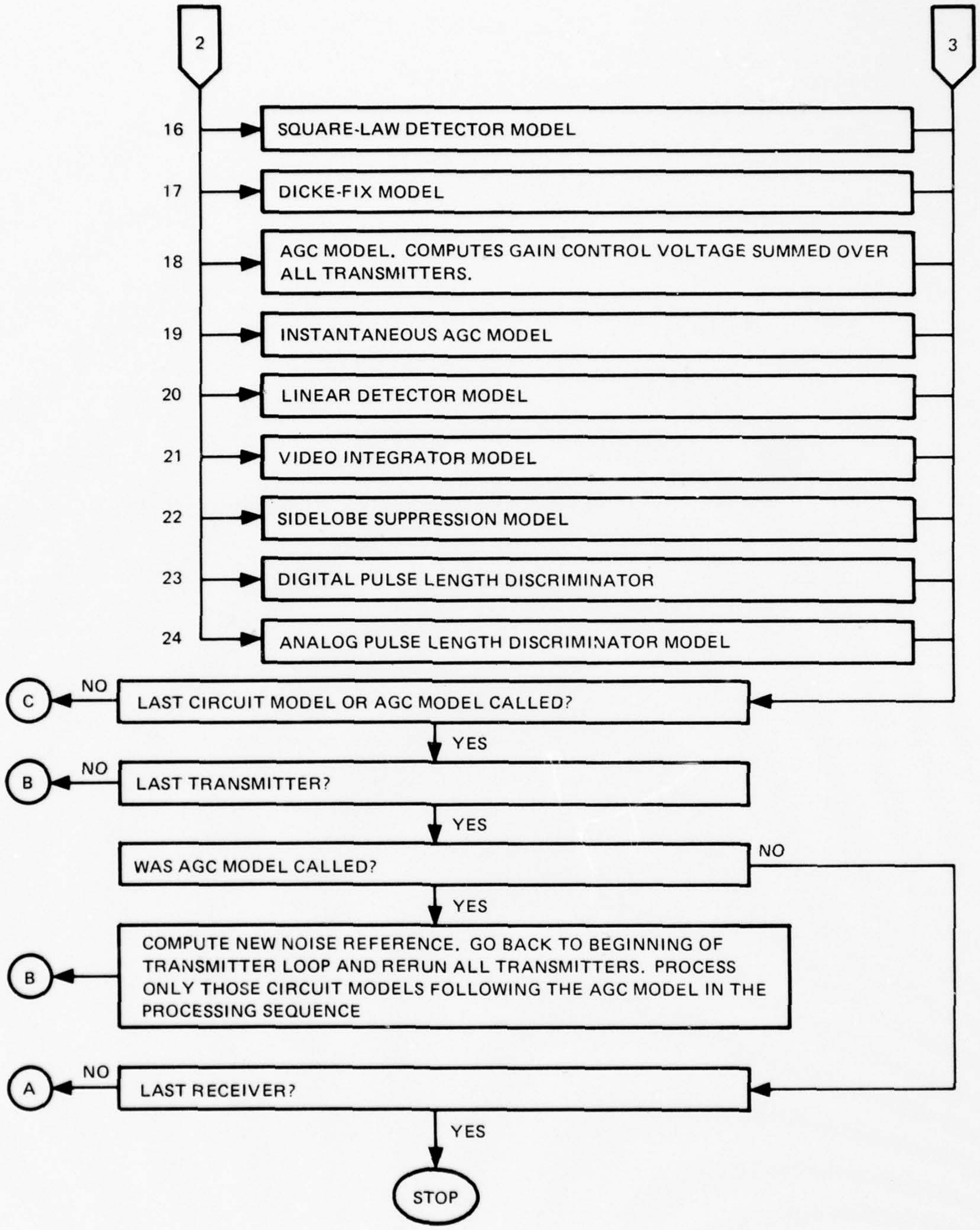

Figure 5. (Continued).

Table 2. Signal Processing Circuit Models Developed by ARC.

Classification of Signal Processing	Signal Processing Circuits
RF	Waveguide
	Mixer
	rf filter
	rf limiter
IF	IF filter
	Linear FM pulse compression filter
	Dicke-Fix
	Noise controlled AGC
	Fast (Instantaneous) AGC
	Detector (Linear and Square-law detectors)
	IF limiter
	Linear-logarithm amplifier
Video	Moving target indicator
	PRF discriminator (coincident video)
	Fast time constant
	Pulse length discriminator
	Video sweep integrator
	Sidelobe suppression
	Video limiter

5.0 THE DEVELOPMENT OF PERFORMANCE DEGRADATION MODELS BY ARC

In general, a radar receiver can be divided into two parts. One is in the area of signal processing and the other is in the area of information extraction. The first area considers receiver processing effects on the interference (or INR). The second area considers the processed interference effects on receiver performance.

The processed interference effects on receiver performance are presented in this section (ref 4). Three models for measuring performance degradation have been postulated by ARC. These models predict the Plan Position Indicator (PPI) detector performance degradation caused by interferences. The models are entitled:

- Delta Equivalent Noise (DEN),
- Detection Delay Time (DDT), and
- Cumulative Reaction Evaluation Method in an Active Target Environment (CREMATE).

In addition, the effect of interference on false alarm rate is investigated. Finally, machine and human detection performances are compared.

5.1 DELTA EQUIVALENT NOISE MODEL

The DEN model determines the increase in target signal level required to maintain the same probability of detection when in the presence of interference. In the model, interference is treated like noise. Using the standard equation for probability of false alarm, an equivalent noise level is calculated for the interference. When added to receiver internal noise, a new noise level is established. The difference in noise levels in decibels is the amount of degradation experienced. Comparison to measured data reveals good agreement and the standard deviation of error is 2.5 dB.

5.2 DETECTION DELAY TIME MODEL

The DDT model determines the increase in detection time for a stationary target on the PPI with the receiver subjected to interference. PPI detection delay time is defined as the number of scans needed to perform initial target detection in an interference environment, relative to the number of scans-to-detect in an interference-free environment. The results of the model were based on a set of PPI detection measurements. The measured data were subjected to a regression analysis to obtain empirical formulas of average numbers of scans-to-detect in the two environments (i.e., interference and interference-free). Subtracting one formula from the other produces the delay time.

The average number of scans-to-detect for an interference-free environment is a function of target signal-to-noise ratio, number of pulses integrated, and receiver bandwidth. Similarly, the average number of scans-to-detect for an interference environment depends on target signal-to-noise ratio, signal pulse width, number of signal pulses integrated, receiver bandwidth, interference-to-noise ratio, interference pulse width, and the number of interference pulses displayed in one azimuth scan of the victim radar.

Two analyses are performed for each environment (interference-free or interference). Analysis I incorporates an optimistic assumption regarding target detection, while Analysis II

uses a pessimistic one. The two approaches bound the value of detection delay time. Analysis I gives the standard deviation of error (σ_E) of 5.4 scans; while σ_E for Analysis II is not defined.

5.3 CUMULATIVE REACTION EVALUATION METHOD FOR AN ACTIVE TARGET ENVIRONMENT MODEL

The CREMATE model accounts for human scan-to-scan dependence in the PPI detection of moving targets. It is based on the concept that the human PPI detection process is cumulative over a number of scans. The model accounts for the average change in signal strength due to target motion. A regression analysis of PPI measurements produces the cumulative probability of detection of a moving target. A Moving Target Cumulative Detection Function is defined as: the probability that a given moving target is detected on or before the nth scan. Using this function, moving target cumulative detection probabilities in both the interference-free and interference environments can be calculated.

5.4 FALSE ALARM RATE

The effect of interference on PPI operator false alarm rate was investigated. The interference parameters selected for this study are interference power level, interference pulse width, interference PRF, and interference duty cycle. The results of this study indicate a trend that false alarm rate is reduced as the interference condition worsens. For examples, false alarm rate decreases as

(1) interference power level increases,

(2) interference pulse width increases,

(3) interference PRF increases, and

(4) interference duty cycle increases.

This trend has been attributed to the operator's over-reaction in response to the undesired signals. No mathematical model is provided for the simulation of the behavior of operator false alarm rate, as affected by interference.

5.5 COMPARISON OF MACHINE, HUMAN, AND THEORETICAL DETECTION

The vast majority of initial target detections, when performed on Naval ships, is accomplished by a radar operator viewing a PPI display. It has been assumed that a machine (or automatic, or threshold) detection model can adequately characterize the performance of human operators.

Machine detection models are generally based on standard mathematical models of noise voltage and signal-plus-noise voltage amplitude densities. These hypothetical probability density functions are then used to make a decision regarding the presence of a target. Basically, a radar video output voltage is monitored and whenever that voltage exceeds a preassigned voltage threshold level a target "detection" is declared. This implies that the energy returned from a target and received by the radar receiver will increase the video voltage level above the ambient fluctuating noise voltage level. The ambient noise causes a trade-off in detection performance, since it also may occasionally exceed the preassigned threshold level and cause a false alarm. Of course, the higher the threshold level the less often the noise will

exceed that level and, consequently, fewer false alarms will occur. On the other hand, a higher threshold level will mean that weak target returns are also much less likely to be detected and, consequently, a lower probability of detection will be obtained.

Machine detection models are based on two assumptions:

a. The probability density functions of noise alone and of signal-plus-noise are known quantities.

b. Probability of detection by the PPI–human process can be determined with reasonable accuracy from a knowledge of these two density functions.

This section presents a preliminary investigation of the truth contained in the two statements above. Three comparisons have been made by ARC.

1. Measured noise-alone voltage amplitude distributions of AN/SPS-10 and AN/SPS-39 have been compared to the theoretical models of linear and square-law detectors. The theoretical density functions for a linear envelope detector and a square-law envelope detector are given as

$$P_L(V) = \frac{V}{N} \exp\left[\frac{-V^2}{2N}\right] \qquad \text{(linear)}$$

$$P_{SL}(V) = \frac{1}{2N} \exp\left[\frac{-V^2}{2N}\right] \qquad \text{(square law)}$$

where

V = the random variable, voltage amplitude

N = noise power prior to envelope detection.

2. Measured machine detection performance has been compared to a theoretical model of machine detection. The theoretical single-pulse detection probability formula is

$$P_d = \exp\left[\frac{\ell n\,(PFA) + 1}{SNR}\right]$$

where

PFA = probability of false alarm

SNR = signal-to-noise ratio

The equation is modified to account for interference by adding the average interference power I to the noise power N. Letting INR be the average interference-to-noise ratio (peak INR times interference duty cycle), the theoretical single-pulse probability of detection becomes:

$$P_d = \exp\left[\frac{\ell n\,(PFA) + 1}{SNR/(1 + INR)}\right]$$

3. Measured human operator detection via the AN/SPS-39 PPI console has been compared to a theoretical model of human detection. To account for the human element in the detection process, the single-pulse SNR of the target is multiplied by the square root of the number of target returns per scan, producing an equivalent SNR to be substituted in the machine detection model. To account for the effects of deterministic interference, it is assumed that deterministic interference behaves like noise. The theoretical model of human detection is given by,

$$P_d = \exp\left[\frac{\ell n\,(PFA) + 1}{\sqrt{n} \cdot SNR/(1 + INR)}\right]$$

where

n = number of target returns per scan.

The conclusions drawn from these comparisons are:

1. The noise-alone distribution comparison results were not totally conclusive, but the indications were that the AN/SPS-10 employs linear envelope detection and the AN/SPS-39 employs square-law envelope detection. The impact of achieving only partial correspondence between measurement and theory is determined after evaluation of the total radar detection model. If the detection model follows measurements closely, then deviation from measurements of noise-alone distributions is not of major concern. On the other hand, where detection model and measurement results diverge, noise-alone distribution analysis becomes an important factor to consider.

2. The measured and theoretical machine detection comparison showed good overall agreement. The average signal-to-noise difference to obtain the same probability of detection was 0.23 dB. Variations from the mean, however, were on the order of 5 to 7 dB, with the greatest errors usually occurring when the average interference-to-noise ratio was high (greater than −10 dB). In this situation, the machine detection model generally predicted that a given detection probability would occur at a lower signal-to-noise ratio than the measurements indicated. It appears that additional work is needed in the area of machine detection performance in an interference environment.

3. According to the mathematical formula chosen for comparison to human operator detection, the probability of detection (with the operator viewing a PPI display) depends on the number of pulses-on-target per scan, the target signal-to-noise ratio, and on the average interference level. The dependence on number of pulses was not possible because the number was fixed at eleven. Comparison of the PPI measurements to machine detection, at false alarm probabilities of 10^{-6} and 3.2×10^{-8}, produced average differences in signal-to-noise ratios for the same detection probability of less than one decibel. The standard deviation was approximately 1.3 dB in both cases. The conclusion is that the probability of detection by human operators can be adequately predicted, by presently available analytical techniques, when a single source of interference is present.

5.6 SUMMARY

Various signal processing circuit models and performance degradation models, which were described in Sections 4.0 and 5.0 respectively, are for search radars when single pulse interference is presented. These models are discussed in detail in (ref 4). The signal processing circuit models have been included in the PARDEG program, but there is no computer code

to describe the performance degradation models presented in this section. Figure 6 summarizes various tasks accomplished by ARC from the completion of the SEMCAM program to the end of 1974.

Further studies by ARC which were tasked by NAVSEC included:

(1) Search radar performance degradation from multiple interference.

(2) Tracking radar (AN/SPG-51C) performance degradation in an EM environment.

(3) Validation of PPI detection performance degradation model.

The results of these studies were assumed by references 12, 13, and 14, but this author has not been able to obtain copies as of this writing.

---

12. Atlantic Research Corporation, Search Radar PPI Performance Degradation from Multiple Interference prepared for NAVSEC under contract no. 75-C-7019, May 1976.
13. Atlantic Research Corporation, Tracking Radar (AN/SPG-51C) Performance Degradation in an EM Environment, prepared for NAVSEC.
14. Atlantic Research Corporation, Validation of PPI Detector Performance Degradation Model, prepared for NAVSEC, under contract no. 75-C-7019.

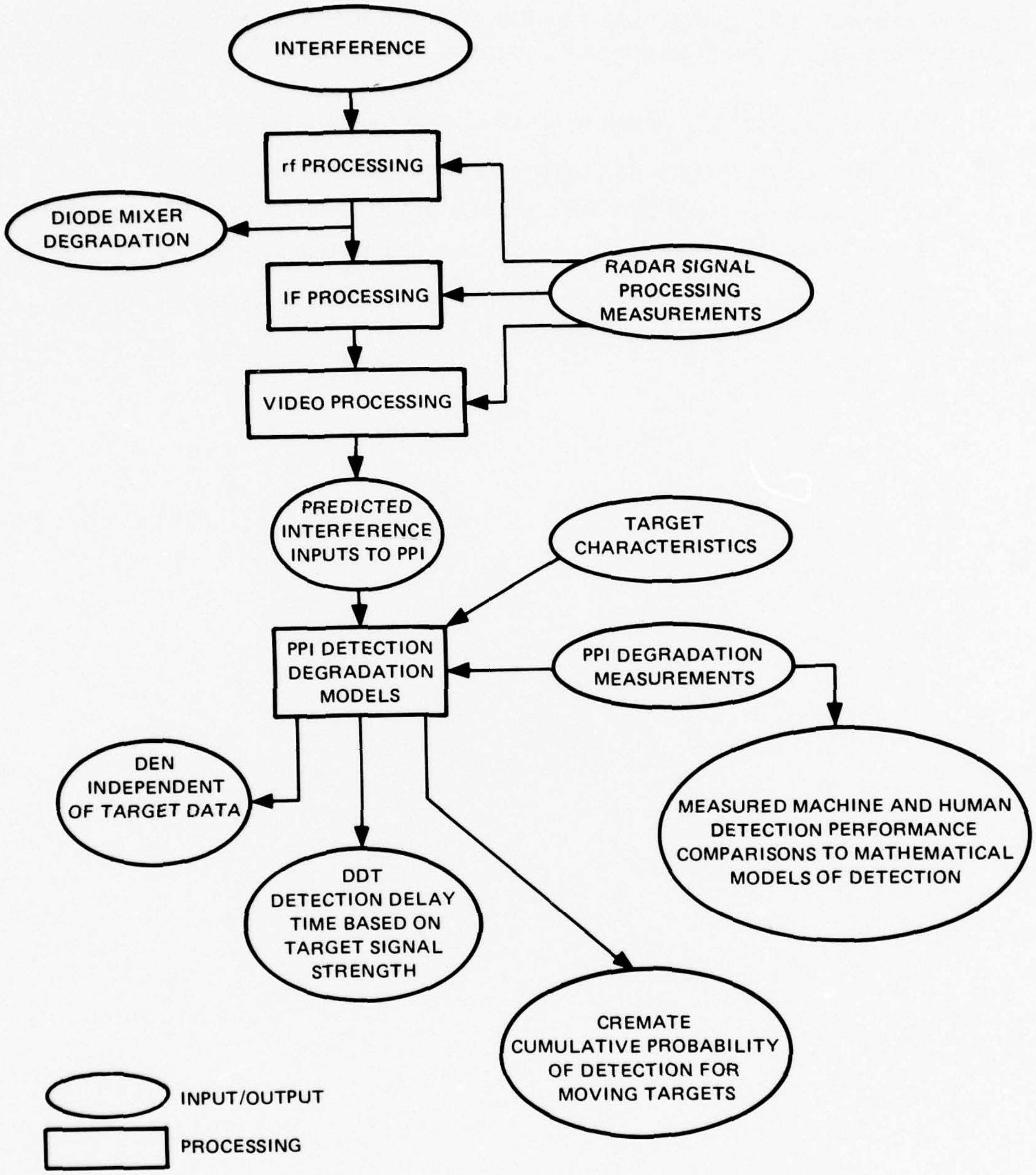

Figure 6. Connectivity of various tasks accomplished by ARC.

6.0 THE DEVELOPMENT OF SIGNAL PROCESSING CIRCUIT MODELS BY ECAC

6.1 INTRODUCTION

In the past, engineers at ECAC have manually performed numerous analyses that addressed potential ECM problems associated with traditional radar systems, as well as modern radar systems such as AN/SPY-1 (AEGIS) and PHALANX (CIWS) (ref 15). Depending on the environment, ECAC has applied the following four types of analyses to rf circuits in all radars:

- on-tune interference,
- adjacent signal interference,
- spurious emission, and
- spurious response.

On-tune interference and adjacent signal interference usually apply to a radar degraded by another radar of the same type. The on-tune interference can cause receiver burnout. The adjacent signal interference may include the combined effects of cross-modulation, desensitization, and saturation. Adjacent signals can cause serious interference because the selectivity for many radars is not as sharp as for communications equipment.

Spurious emissions also may cause interference between radars which are in geographic proximity. Spectrum signatures usually are not available, so the ECM engineer often must resort to rough approximations to estimate the spurious emission spectrum. The emission spectrum of the final power amplifier tube (e.g., klystron, magnetron, or TWT) is the usual starting point. Other factors used to estimate the output spectrum are harmonic suppression of the transmitter output, pulse repetition rate, pulsewidth and shape, fundamental frequency, and power output. It often is assumed that harmonic outputs have a spectrum similar in shape to the spectral region around the fundamental. Sometimes it is assumed that transmitter emissions appear noise-like to the receiver.

The spurious responses of a victim receiver may sometimes be found in a spectrum signature measurement. However, the ECM engineer usually uses the image suppression of the receiver, local oscillator frequencies, etc., to predict the spurious responses.

In addition to the above methods for analyzing rf circuits, ECAC has developed a handbook of techniques for analyzing special (or signal processing) circuits (ref 16). This handbook discusses the analysis techniques available within ECAC that pertain to the effects of radar receiver special circuits on the processing of interfering signals.

6.2 SIGNAL PROCESSING CIRCUIT MODELS

ECAC studied signal processing circuits located in the IF and video stages such as sensitivity time control (STC), fast time constant (FTC), moving target indicator (MTI), and sidelobe cancellation. These circuits are categorized as constant false alarm rate (CFAR), discrimination, velocity filtering, and receiver devices and are listed in table 3.

15. Moser PJ, Survey of Radar Analysis Techniques, ECAC report, 11 October 1977.
16. Lesniakowski T, Special Circuits Survey, ECAC, ECAD-HDBK-77-23, February 1977.

Table 3. Signal Processing Circuit Models Developed by ECAC.

Category	Circuit
CFAR	Adaptive detection
	Automatic video noise limiting
	Dicke fix
	Dicke fix log
	Logarithmic amplifier
	Sensitivity time control
Discrimination	Coincidence decoder
	Correlators
	Fast time constant
	Integration { Analog
	Common digitizer
	Pulse interference eliminator
	Pulse interference suppression and blanking
	Pulse width discriminator
	Spread spectrum { Matched filter
	Linear FM pulse compression
	Phase-coded pulse compression
Velocity Filtering	MTI
	Pulse doppler
Receiver Devices	Automatic gain control
	AN/FST-2 data processor
	IFF/SIF decoder
	Indicators
	Parametric amplifier
	Peak riding detector
	Peak selector (analog)
	Sidelobe cancellation
	Video data quantizer

Each of these circuits is described with respect to its effect on interference, documentation status (ECAC published), external information required (input requirements), assumptions/limitations, computations with the model, and finally, the extent of model/prediction results validation. The assumptions and limitations apply to both modeling simplifications and applicability of these models to certain interfering signal parameters such as pulsewidth, PRF, etc.

ECAC does not consider the combined effects of more than one signal processing circuit that a radar system may be comprised of. Tracking radar was not included (except for discussion of AGC) in the survey, but publications on modeling of tracking radar systems can be found in references 17 through 20.

6.3 SUMMARY OF ECAC MODELING CAPABILITY

A brief summary of receiver processing effects on interference and some additional comments, for each circuit considered in the handbook of techniques for analyzing special circuits (ref 16), are presented in table 4.

General guidelines are provided for CFAR devices, devices using limiters, and devices that have a processing gain. CFAR devices are usually designed to respond to an average power, and thus, are not affected by low-duty-cycle pulsed interference. Devices using limiters prevent low-duty-cycle pulses from causing false alarms. Limiters can be captured by high-duty-cycle interference when $S/I \leqslant 0$ dB; in which case, the receiver is desensitized. Devices that have a processing gain (PG) (e.g., matched filters, correlators, chirp, pseudo-random noise, PSK, pulse Doppler) will reduce peak interference and, consequently, the interference will usually have a low probability of causing a false alarm.

Table 4. Modeling Capability Summary of Signal Processing Circuits.

Circuit	Effectiveness to Interference	Comments
Adaptive Detection	Interference effects may decrease the probability of detection.	The mean level detector is only one of many similar CFAR techniques (noise estimation) analyzed with respect to EMC considerations. The mean level detection model only considers single pulse interference.
Automatic Video Noise Limiter (AVNL)	The circuit will not alter the effects of interference signals unless these interference signals occur during the sampling period when video gain control is in effect.	This circuit does not appear in many present day radar systems.
Dicke Fix	This system is effective against signals whose spectrum is wide, compared to the narrow band amplifier or off-tune pulses.	The model has been developed fairly recently. The circuit is found in several radar systems. A measurement test setup description is available and some limited measurements have been performed.

17. Aasen M, Methods for Predicting the Effects of Interference on Tracking Radar, ECAC, ECAD-TR-63-2, August 1962.
18. Showalter GL, F-14A/AWG-9 Radar/Task Force Environment EMC Analysis, ECAC, ESD-TR-71-095, June 1971.
19. Box F, Cuthbertson J, Newhouse P, and Schwartz L, Tactical Electromagnetic Environment Evaluation Model (TEEM); Phase II, ECAC, ECAC-PR-73-031, July 1973.
20. Baker A, Cuthbertson J, Krueger R, An EMC Analysis of the AN/TPS-37 Radar System, Volume 1, ECAC, ECAC-PR-74-049, January 1975.

Table 4. (Continued).

Circuit	Effectiveness to Interference	Comments
Dicke Fix Log	The circuit is effective against both wide-band or narrow-band interference.	The model is basically the same as above, with the logarithmic amplifier following the Dicke Fix circuitry.
Logarithmic Amplifier	For inputs of different pulse widths or off-frequency signals, the processing of the log-amp receiver is similar to a normal IF amplifier.	A validation measurement test set up description is available.
Sensitivity Time Control	Not primarily an interference reduction feature.	Project engineer is generally concerned with worst case condition (minimum sensitivity), which is prevalent 75% of the period.
Coincidence Decoder	Dependent on the particular circuit used, it can be effective against long pulse interference.	Models consider multiple-source interference only.
Correlators	Very effective in eliminating non-synchronous signals.	Measurement data is available, but no effort has been made to demonstrate how accurately the theoretically developed model follows the measurement results.
Fast Time Constant	Can reduce on-tune interference pulses longer than the design pulse-width by approximately 3 dB.	Not too effective against pulse interference.
Integration-Analog	Circuit may decrease the number of false alarms, dependent on the relationship between interfering pulse repetition frequency and designed pulse repetition frequency.	The circuit is still found in current radar systems, an extension of the basic model has recently been completed and there is a validation measurement, test setup description available.
Integration-Common Digitizer	Very effective against non-synchronous PRF.	Circuit is found in current generation ARSR radars. The approach taken assumes that the probability of each interfering source, producing at least one pulse in a sliding window of size "m", is a constant proportional to the effective duty-cycle.
Pulse Interference Eliminator (PIE)	Effective in removing those pulse signals that are not precisely on the operating frequency (separated in frequency by more than the half-bandwidth of the design pulse spectrum).	It is still in use in many military and civil long range Air Traffic Control radars in CONUS. Because of assumption made in the development of the math model, the model has limited application.

Table 4. (Continued).

Circuit	Effectiveness to Interference	Comments
Pulse Interference Suppression and Blanking (PISAB)	Effective against pulse interference which is not synchronous with the design signals. However, it is possible to lose a valid return which just happens to occur at the wrong time.	It was found that the circuit does not appear in many present day radar systems. Because both interference as well as desired signals can be eliminated, the advantages of this circuit are somewhat reduced.
Pulse Width Discrimination (PWD)	PWD is very effective against pulse type interference, when the pulse widths encountered are wider than the design pulses of the system, but not too effective against off tune pulses.	For ECM purposes, the project engineer generally is faced with an off-tune interference situation and for that reason this circuit may not be too effective.
Spread Spectrum, Matched Filter	Depending on the BT ($B \triangleq$ emission bandwidth, $T \triangleq$ pulse width) product, the matched filter can provide significant S/I improvement.	This is a generalized model where the pulse compression model is a particular case. Would recommend, for pulse compression case, using the more current models as previously mentioned.
Spread Spectrum, Linear FM Pulse Compression	Peak signal-to-interference improvement can be obtained for both on-tune and off-tune interference signals.	Models are available (documentation on most recent model to be issued soon) that can help the project engineer for determining the interference effects to a pulse compression receiver. Limited measurement data on one of the earlier models is available.
Spread Spectrum, Phase-Coded Pulse Compression	Same as above.	Although a model for phase coded pulse compression filter is available, the determination of the interfering pulse waveshape entering the filter must be determined before the amount of rejection can be estimated.
MTI	Considering both advantages and disadvantages of the circuitry, coherent MTI does not appear to be too effective in interference reduction.	Circuit does not seem too effective against pulse interference. Modeling of other types of MTI systems (i.e., Vector) have not been performed.
Pulse Doppler	Circuit is particularly effective against non-coherent, non-synchronous interference.	Several models are available, but none have been validated.

Table 4. (Continued).

Circuit	Effectiveness to Interference	Comments
Automatic Gain Control	The response of the AGC to interference signals can cause receiver capture receiver densitization, and increased tracking error in tracking radars.	Limited measurements have been made on this model and the results appear to agree with theoretical predictions.
Data Processor	The AN/FST-2 data processing system was found to be very effective against pulse interference signals.	The AN/FST-2 is only one of several types of data processing systems analyzed with respect to ECM considerations.
IFF/SIF Decoder	The replies are complex enough that the decoder will never accept random pulse interference as a valid reply. The problem which arises, is that replies from transponders triggered by other interrogators enter the receiver and are accepted as valid replies by the decoder.	There is a more current model found in the AIMS prediction model that has not been considered for this task.
Indicators	The MDS or threshold power level for a single pulse was determined experimentally to be 12-dB above the conventional MDS determined for a synchronized pulse train.	The analytical model was empirically related to the PPI photographs with the measured pulse amplitude distribution data. For another approach in determining radar display degradation, see reference 26.
Parametric Amplifier	Not an interference reduction technique. Affords little rejection to interference.	A validation measurement test set up description is available.
Peak Riding Detector	Loss in desired signal strength may cause reduced service range of the system.	Other than in TACAN, receivers have not found this type of circuit in wide use.
Peak Selector-Analog	Interference affects the false alarm time and probability of detection.	New generation radars use digital techniques.
Sidelobe Cancellation	Rejection capabilities on the order of 20-dB (dependent of interfering signal level) for continuous wave type interference can be obtained. The video sidelobe canceller is not too effective against pulse interference. However, other schemes (e.g., IF SLC) have reported interference rejection up to 18-dB for sidelobe pulse interference.	Only considers a single interfering source.

Table 4. (Continued).

Circuit	Effectiveness to Interference	Comments
Video Data Quantizer (A to D Converter)	For the two types of A-to-D converters considered, the false alarm rate of the noise averaging quantizer increases linearly with interfering signal repetition rate; while, rate-comparing quantizer essentially maintains the desired rate for interfering PRF's up to the desired rate.	The A to D converters are found in present generation radars and this area does not seem to have been explored fully.

7.0 THE DEVELOPMENT OF PERFORMANCE DEGRADATION MODELS BY ECAC

ECAC has made continuous efforts to develop a more realistic radar system performance model. Some of the major efforts include:

- Establishment of a scope interference level index for PPI interference prediction
- An approach to calculate system performance score using Monte Carlo simulation
- Survey of literature on radar operational degradation
- Establishment of permissible interference levels.

These efforts are briefly presented in the following sections.

7.1 PPI INTERFERENCE PREDICTION

Since 1958, the Air Defense Command has standardized, a five level classification of interference on manually operated equipments, in its specification for interference reporting. These five levels range from Condition 1, having little or no interfering pulses on the scope; to Condition 5, which has heavy interference clutter over most of the scope face. However, the classification of interference by scope condition has three limitations:

1. The appearance of interference on the PPI is a dynamic event; not a static event, as captured by still photograph.
2. There are more types of interference than are represented by published pictures.
3. The pictures are not related to the physical variables of the interference conditions which give rise to the PPI appearance.

The last limitation was reduced in an early ECAC effort reported by Katz (ref 21) in 1965. Katz assumed that the effects, both in degradation of operator performance and in degradation of target detection range, are a function of clutter intensity. Clutter intensity is defined as the product of scope cluttered area and the brightness (luminance) of the cluttered area. He then determined clutter intensity as a function of the interference pulse distribution input to the PPI display. Therefore, interference pulse distribution can be related to the five interference scope conditions.

A scope interference level index, N, is defined as

$$N = \sum_{i} Q_i \,(P_i - P_{MDS}) \times 10^{-4}$$

where

Q_i = number of pulses per scan at power level P_i

P_i = peak power of pulse interference signal in dB/m

P_{MDS} = pulse power in dB/m, necessary to produce a minimum discernible single pulse on PPI. Note, that the MDS for a single pulse is 12 dB above the conventional MDS determined for a synchronized pulse train.

21. Katz L, PPI Interference Prediction IEEE Trans. on Electromagnetic Compatibility, June 1965.

$P_i - P_{MDS}$ has maximum value of receiver dynamic range. The limits of N corresponding to each scope condition are determined. Table 5 shows equivalence of scope condition and N numbers. This study provides a numerical measure which accounts for the fact that the number of pulses per PPI scan, together with their amplitude distribution, are closely related to estimates of degradation made of operator's judgments of PPI display. Katz's model is useful for situations in which all radars are uniformly scanning, fixed in frequency, and in which the victim is displaying raw video. Katz's model does not consider pulse width, which can also influence the appearance of the blips on the PPI display.

Table 5. Equivalence of Scope Condition and N Numbers

PPI Scope Condition No.	Limits of N
1	0 to 3.7
2	3.8 to 9.4
3	9.5 to 14.7
4	14.8 to 25.2
5	25.3 and over

7.2 COSAM-TYPE APPROACH

In 1971, Lustgarten of ECAC presented a COSAM-type approach for computing system performance score (SPS) for a limited class of radar to radar interactions, namely, simple search radars and simple tracking radars (ref 22). However, no computer program has been written to realize this approach.

Monte Carlo simulation was suggested to generate probability distributions of average interference energy per scan (for search radars) and interference duty cycle (for tracking radars). The interference average energy per scan is the product of peak power, pulse width and pulse rate per scan; while the interference duty cycle is the product of pulse width and interfering pulse rate. Given the distributions and threshold values, it will be possible to calculate system performance score which is defined as the probability of not exceeding the thresholds.

Lustgarten proposed that −105 dB/j (1 joule - 0 dB/j) would be a reasonable threshold value for energy per scan for search radars. As for tracking radars, a duty cycle of 0.05 would represent a reasonably conservative operational degradation threshold.

22. Lustgarten MN, An Approach to the Radar Operational Degradation Problem, ECAC, ECAC-TN-71-34, July 1971.

7.3 SURVEY OF LITERATURE

In 1973, ECAC did a survey of literature on radar operational degradation (ref 23). Major findings and recommendations of this survey are listed below:

1. This literature search resulted in a cumulative bibliography of the available literature on operational degradation in radar systems.

2. In performing this search, it became clear that the problem of operational degradation had not previously been addressed in the manner which is believed to be necessary. For example, although a great deal of work has been done on estimating tracking error and on the performance of human operators exposed to various types of noise jamming, only one study could be found which treated the case involving pulsed interference on PPI displays (ref 24).

3. In general, a comprehensive program of measurements in the area of radar operator performance degradation, due to pulsed electromagnetic interference (EMI), is required. The program should consider major radar functions and should be coordinated with the various military services and civilian agencies to ensure that realistic operating conditions are utilized during the measurements.

4. A simulation procedure should be used, employing an interference scenario which is realistic and contains all levels of interference from "no interference" to "extremely severe" interference. (Numerous ECM tests have been made using simulation procedures.)

5. Design of the scenario, including the use of realistic targets, should be made in conjunction with an agency which has had considerable experience in human engineering; since, the human factor is believed to be the primary element in determining meaningful measures of radar performance. (The Articulation Score and Articulation Index measures, developed to measure voice degradation, are cited as analogous efforts.)

6. A video tape of the interference/desired target scenario should be made, so that a large sample can be secured.

7. At a later date, the use of a "visual recognition" model, similar to Bailey's (RAND Corp) model (ref 25), should be considered.

7.4 ESTABLISHMENT OF A PERMISSIBLE INTERFERENCE THRESHOLD

Based on the recommendations of the literature survey of Section 7.3, ECAC tasked the Calspan Corporation to perform a study in the period of December 1974 to July 1976. The objective of the study was the measurement of performance degradation experienced by search radar operators, utilizing plan position indicators (PPI), when the radar was subject to electromagnetic interference. The study was conducted in two phases.

In Phase 1 of the study, the experimental parameters were defined, the required hardware and software was developed, and the capability to make the measurements was demonstrated. In Phase 2, the performance degradation of ten experienced operators in

---

23. Lipman P, and Lustgarten M, Survey of Literature on Radar Operational Degradation, ECAC, ECAC-TN-73-15, July 1973.
24. Hudson EL, Search Radar Performance Degradation, RADC-TR-65-539, May 1966.
25. Bailey HH, Target Detection Through Visual Recognition: A Quantitative Model, Rand Corporation RM-6158-PR, February 1970.

twelve test scenarios was measured. The recorded experimental data were supplied to ECAC for data reduction and statistical analysis. ECAC then used the results to establish a permissible interference threshold (ref 26, 27).

Figure 7 shows the experimental parameters defined in Phase 1 of the study. Five potential performance measures are indicated on the right.

7.4.1 Performance Measures

Missed Targets. A miss is counted when delay time equals the period between target introduction and disappearance or between introduction and end of test segment.

Missed targets represent a relatively clear cut measure of performance degradation. More targets were missed in the presence of interference than in associated clear segments.

Acquisition Time. Acquisition time is defined as time after a new aircraft should first be visible (target signal to receiver noise exceeds 4 dB), to the time of the operator's first report. This time is measured in seconds.

The measured data indicate that interference apparently affected operator performance adversely on acquisition time. When pulse counts were relatively low, acquisition time performance was adequate; while, when counts were high, operators tended to take more time to acquire one or more targets.

Normalized Lost Time. This measure was devised to estimate the operator's target up-dating performance. That is, once the target was acquired, the operator was required to continually up-date target position as the "blip" moved across the scope. The normalized lost time measure provides a relative estimate of how well the operator performed this task.

An allowable update time (t_{ua}) is specified, 25 sec. The precise value chosen is not significant, since it is to be used for comparison purposes. For practical purposes, a value larger than 15 sec and smaller than, say, 40 sec was required.

Then, a "lost time" interval (Δt_ℓ) is calculated, as follows:

$$\Delta t_{\ell 1} = t_2 - t_1 - t_{ua} \qquad \text{If } t_2 - t_1 \leq t_{ua},\ t_{\ell 1} = 0$$

t_1 is the time of the first report; t_2 is the time of the second report, etc. Similarly:

$$\Delta t_{\ell n} = t_{n+1} - t_{na} - t_{ua}$$

and:

$$t_\ell = \sum_{1}^{n} \Delta t_\ell$$

---

26. Lustgarten MN, and Grigg RD, Effects of Radar Interference on Search Radar Operator Performance, paper presented at 1977 IEEE International Symposium on Electromagnetic Compatibility, in Seattle, Washington, 2-4 August 1977.
27. Pierstorff BC, Rosenthal P, and Hanes CM, Simulation of Radar/Radar Interference at RF for the Evaluation of Interference Effects on Operator Performance, paper presented at IEEE 1977 International Symposium on Electromagnetic Compatibility, in Seattle, Washington, 2-4 August 1977.

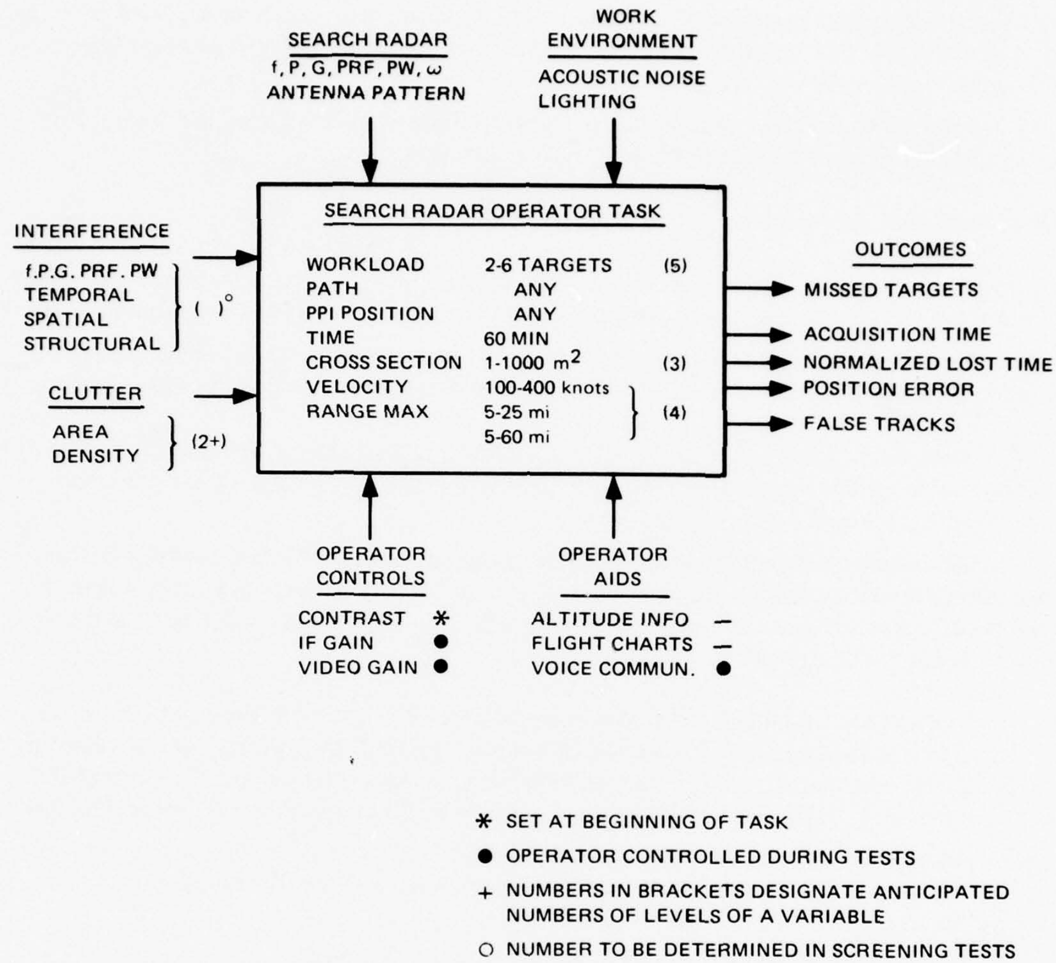

Figure 7. Test variables for the evaluation of interference effects on operator performance.

The normalized lost time $t_{n\ell}$ is defined as:

$$t_{n\ell} = \frac{t_\ell}{t_{n+1} - t_1}$$

A comparison of normalized lost time data, relative to clear and interference scenarios, indicates that the effects of interference were minimal.

Position Error. A comparison of position error data relative to clear and interference scenarios indicates that the effects of interference were essentially negligible. In fact, there were strong indications of negative correlation. That is, on the whole, performance relative to this parameter was better in the presence of interference than in clear situations. After the operators had acquired the targets, their position accuracy was generally better during interference scenarios than during clear scenarios.

False Tracks. A false target is counted when the position error from a target of at least 4 dB S/N exceeds 7 mi. at the 60 mi. range.

The exercise indicated that the operators would, occasionally, declare a target when no target was present in the area of the reported location. A review of the false track reports indicates a strong tendency for the operators to make more false track reports in clear situations than during periods when interference was present. One possible explanation for this phenomenon is that operators become more cautious than normal when interference is present, therefore, tending to produce fewer reports on possible targets. Consequently, the false track parameter will not be used to estimate permissible interference levels.

7.4.2 Displayed Pulse Count

Displayed Pulse Count was used to count the number of interference pulses per scan for a relatively large number of scans. The average value and the standard deviation were recorded for each interference scenario. The counter threshold was set at a level 16 dB above noise level.

The displayed pulse count is obtained by multiplying the average count by the factor R × PRF/93 000. (R is the maximum scope range in statute miles, PRF is the victim radar PRF.) The actual number of pulses observable on the scope is somewhat larger, since uncorrelated pulses can be detected visually at a level approximately 10 dB greater than noise. Methods are available for translating the displayed pulse count value into pulses per sec or pulses per scan at various levels above noise.

The displayed pulse count is a useful criterion to determine which interference levels would, or would not, be permissible. If in the same target scenario, operator performance did not differ significantly, with or without interference, then that level of interference had no effect on operator performance and a permissible displayed pulse count can be established. The displayed pulse counts for various scenarios were recorded. The scenarios were divided into the following six groups; namely, one search radar, two search radars, three search radars, five search radars, one height finder, and one height finder and one search radar.

7.4.3 Permissible Interference Threshold

Table 6 summarizes the findings of the study relative to permissible and "not permissible" displayed pulse counts. The lowest "not permissible" pulse count is specified for each of the six groups in the first column. In the second column, the highest permissible level is provided, where applicable.

The results of this study indicate that a permissible search radar interference threshold will be a function of the number and types of interfering radars (e.g., search radars or height finders) as well as the average number of interfering pulses which appear upon the PPI display.

The study also indicates that in no case was operator performance significantly affected when a displayed pulse count of 100 or less (due to one or more search radars) was recorded.

Consequently, until further tests are conducted, it is concluded that a displayed pulse count of 100 should be adopted as an interim permissible interference threshold, relative to search-radar to search-radar interactions.

Table 6. Summary of Permissible and "Not Permissible" Levels

Type Interference	Lowest "Not Permissible" Level	Highest Permissible Level
one search radar	846	144
two search radars	646	113
three search radars	250	125
five search radars	740	
one height finder	117	
one height finder & one search radar	176	

7.5 FUTURE WORKS

ECAC has concentrated its efforts on the area of radar operator performance degradation due to pulsed interference. It was found that missed targets, acquisition time, and normalized lost time can represent operator performance measures in an interference scenario. A permissible interference threshold in terms of displayed pulse count was suggested. If the displayed pulse count is less than 100, the performance degradation of a radar operator viewing the PPI display will be tolerable.

However, ECAC has not investigated the interference effects on machine (automatic) detection and the accuracy of the target position estimated. Future Navy radars will use machine detection and tracking systems. It appears necessary to have further studies on the performance degradation of modern radars using machine detection and tracking systems in an interference environment.

As it was described in Section 5.5, ARC suggested a machine detection model which treated the average interference power as noise. Using this model, machine detection performance can be predicted moderately well in interference-free and low-level interference (the average interference power level is at least 10 dB below noise) environments. ARC concluded that additional work is needed in the area of machine detection performance in an interference environment.

8.0 MODELS WITH ENVIRONMENTAL EFFECTS

The major factors affecting radar performance seem to be equipment, operator, and environment. The effects of equipment (e.g., signal processing circuits, display) and operator (i.e., human factors) were described in Sections 3.0 through 7.0. However, SEMCAM and PARDEG do not consider environmental effects. Neither the efforts of ARC or ECAC address environmental effects. This section presents two models which consider the environmental effects on radar detection capability. These environmental effects include the effects of sea clutter, wind, rain, multipath, and atmospheric refraction on the detection capability of a radar. The two models are:

- Surveillance Radar Systems Evaluation Model (SURSEM)
- Search and Detection Radar System Performance Model with Environmental Effects (SADRSPMWEE)

8.1 SURVEILLANCE RADAR SYSTEMS EVALUATION MODEL

8.1.1 Program Description

SURSEM was developed by the Naval Research Laboratory with the objective of providing the Navy with a fully described, user-oriented computer model of a surveillance radar (ref 6). SURSEM calculates radar single-scan and cumulative probability-of-detection values as a function of target range and orientation. The radar operates within a specified scenario, defined by the user to include the target to be detected; up to nine additional sources of jamming radiation; and an optional environment of wind, rain, and multipath.

SURSEM has been constructed as a modified time-step model. The time steps involved are determined by the elapsed time between radar scans illuminating the target. The surveillance radar under examination is characterized by its radar scan modes. A radar scan mode is a device defining radar operating characteristics for the illumination of a specific geometrical region. Typical radar scan modes include long-range search; high-angle, low-energy search; burn-through; and horizon scan. An engagement (i.e., in the limited sense of a target flying into the detection range of the stationary surveillance radar along a predetermined course, and the radar attempting to detect the target during its flight) is initiated at the time the target leaves its initial position and is terminated when the target reaches its final position. At the onset of the engagement (i.e., when the target leaves its initial position), the time is determined at which each operational radar scan mode will first illuminate the target. The mode corresponding to the smallest time is selected as the initial scan mode, and its time of occurrence becomes the current engagement time.

The position and orientation of the target at the current time are calculated under the assumption that the target follows a linear flightpath at constant speed. The position and orientations of any other defined targets, which are treated as additional sources of jamming radiation, are determined in the same manner.

The probability that the radar will detect the target, during the selected radar scan, is calculated by means of the user-designated Marcum-Swerling cross-section model (ref 28). SURSEM is concerned with the evaluation of surveillance radars and has no provision for

28. Marcum JI, and Swerling P, Studies of Target Detection by Pulsed Radar, IRE Trans. IT-6, No. 2 (1960).

target tracking. Scan-to-scan independence is assumed in the calculation of the cumulative probability of detection.

8.1.2 Environmental Effects

The effects of wind, rain, and multipath on the detection capability of the radar are included in the model through the specification of the following environmental input parameters:

(1) Wind speed in knots

(2) Height of wind-speed measurement in thousands of feet

(3) Multipath indicator (0 or 1, where 0 = no multipath and 1 = multipath)

(4) Rainfall rate in millimetres-per-hour.

The wind speed and the height at which it is measured are used to determine the sea state in the calculation of the sea-clutter return. The multipath indicator determines whether it is necessary to consider multipath effects. If it is necessary, a pattern-propagation factor is computed for a specific target. This pattern-propagation factor accounts for the contribution of multipath effects on the desired signal energy and the jamming energy. The rainfall rate permits the calculation of the rain-attenuated signal energy and the contribution of rain backscatter to the total noise energy.

8.1.3 Output

An engagement begins at the time the primary target leaves its initial position. From this time until the time the target reaches its terminal position, the model considers each radar scan mode and corresponding scan time in turn and selects, for operation, the next mode that will illuminate the target. For each scan mode selected, the following fifteen output values, constituting a line of output data, are generated:

(1) Scan counter

(2) Scan mode number

(3) Time of scan occurrence in seconds (relative to engagement initialization at time 0)

(4) Slant range of target from radar in thousands of feet

(5) Elevation angle of target in degrees

(6) Azimuth angle of target in degrees

(7) Target cross section in square metres

(8) Multipath pattern-propagation factor in dB (calculated by subroutine MULPTH)

(9) Signal energy in dB (with respect to a joule)

(10) Ambient noise in dB (with respect to a joule)

(11) Clutter energy in dB (with respect to a joule)

(12) Jamming energy in dB (with respect to a joule)

(13) Signal energy-to-noise energy ratio in dB

(14) Single-scan probability of detection

(15) Cumulative probability of detection

The sequential generation of output data for each occurrence of selected scan modes terminates when the target reaches its final position, thereby, ending the engagement.

8.1.4 Future Works

SURSEM considers the effects of interference from a hostile environment, but not the interference from co-site radars. It addresses the effects of wind, sea-clutter, rain, and multipath on the detection capability of a surveillance radar.

NRL will change and expand SURSEM as the result of application of SURSEM to an increasing variety of problems. Some areas of interest for the future modification of SURSEM have already been identified by NRL and include the following:

(1) Signal processing integration of MTI processor model into SURSEM, as well as the development and incorporation of other signal-processing options, such as pulse-compression and pulse-Doppler techniques;

(2) Detection confirmation of greater detail in the modeling of the process that confirms the detection of a potentially detectable target;

(3) Area clutter: more faithful rendition of the effects of sea state, shadowing, and polarization on the area clutter return over a wide range of pulse widths;

(4) Refractive-index models: inclusion of an exponential refractive-index model;

(5) Point signals development of an empirical point-scatterer model and modeling of polarization effects;

(6) Volume clutter: inclusion of a chaff model; and,

(7) Antenna pattern: improved sidelobe modeling and computation of the horizontal gain pattern factor when considering target detection with discrete-beam-forming radar.

Future radars will use automatic detection and tracking systems; consequently, probability-of-detection values are insufficient for evaluating system performance. For instance, in a scenario involving a target raid, questions arise as to whether the multiple targets can be resolved, how accurate the position estimates are, and whether the correct tracks can be initiated. To solve some of these problems, SURSEM has been modified recently into a Monte Carlo simulation that produces target detections and estimates of position. This Monte Carlo program, called the Surveillance Radar Detection (SURDET) Program (ref 29), can be used as the input for the Multiple Radar Integrated Tracking (MERIT) program (ref 30) to solve some of the proposed questions.

8.2 SEARCH AND DETECTION RADAR SYSTEM PERFORMANCE MODEL WITH ENVIRONMENTAL EFFECTS

8.2.1 Program Description

The Search and Detection Radar System Performance Model with Environmental Effects (SADRSPMWEE) was developed by Naval Weapons Center (refs 7, 8). This model

29. Davis LC, and Trunk GV, Surveillance Radar Detection (SURDET) Program, NRL Report 8228, 11 August 1978.
30. Wilson JD, a Multiple-Radar Integrated Tracking (MERIT) Program, NRL Report 8200, 3 April 1978.

assesses the effects of the environment on search and detection radar systems and calculates radar target detection probabilities as a function of target range in a maritime scenario. The scenario is specified as input parameters to the SADRSPMWEE program which includes radar parameters and target parameters. These parameters are described as follows:

Radar Transmitter Parameters

(1) Peak transmitter power,

(2) Transmitter frequency,

(3) Pulse repetition frequency,

(4) Pulse length.

Radar Receiver Parameters

(1) Type of receiver coupling circuit (single-tuned with one through five stages, transitionally coupled double-tuned or stagger-tuned with two tuned circuits, staggered triple, staggered quadruple, staggered quintuple, gaussian),

(2) Type of pulse integration (no integration, incoherent integration, coherent integration, eye/scope integration),

(3) Number of pulses integrated ,

(4) Type of thresholding (no constant false alarm rate, constant false alarm rate),

(5) Quality of blip (degraded quality blip, good quality blip, automated system),

(6) Receiver noise figure ,

(7) Sub-clutter visibility,

(8) Probability of false alarm in noise only,

(9) Pulse compression ratio,

(10) System losses,

(11) Number of blips that must be detected before detection affirmation can occur,

(12) Number of scans that are allowed in order for detection affirmation to occur,

(13) Maximum range of radar system.

Radar Antenna Parameters

(1) Type of antenna aperture (rectangular aperture, elliptical aperture) ,

(2) Type of polarization (horizontal polarization, vertical polarization) ,

(3) Type of antenna platform (stabilized platform, unstabilized platform) ,

(4) One-way power gain ,

(5) 3 dB azimuthal beam width,

(6) 3 dB elevation beam width,

(7) Mean antenna altitude,

(8) Time per scan ,

(9) Mean bore sight angle.

Target Parameters

(1) Type of target scintillation (non-scintillation swerling type targets) ,

(2) Type of flight path (constant altitude and constant velocity flight path, other flight paths not implemented yet) ,

(3) Initial target altitude ,

(4) Target cross-section,

(5) Mach number of target (the ratio of target velocity to sound velocity) ,

(6) Direction of the target in points of compass.

8.2.2 Environmental Effects

Environmental sub-models that simulate the effects of atmospheric refraction, atmospheric attenuation, sea-state, clutter, target scintillation and multipath have been incorporated into the SADRSPMWEE program. The environmental parameters that users have to specify as the input to the program are:

(1) Type of atmosphere (tropical atmosphere, midlatitude-summer atmosphere, midlatitude-winter atmosphere, subarctic-summer atmosphere, subarctic-winter atmosphere, the U.S. standard atmosphere, a user-defined atmosphere, linear refractivity profile, exponential refractivity profile, bi-linear ducting atmosphere),

(2) Type of weather (e.g., clear, rain, hail, clouds, fog, ice crystals. Currently, this parameter is not implemented in the program yet, type of weather is assumed to be clear),

(3) Type of earth's surface (sea water surface with sinusoidal roughness, sea water surface with stepped roughness, fresh water surface with sinusoidal roughness, fresh water surface with stepped roughness, desert surface with sinusoidal roughness, desert surface with stepped roughness),

(4) Degree of surface roughness (sea state of a water surface),

(5) Beaufort wind scale factor,

(6) Number of targets on radar screen (at the present time this number must be set to 1),

(7) Earth's surface temperature,

(8) Direction of the wind in points of the compass,

(9) Direction of the wave in points of the compass.

These input parameters are then used to calculate the environmental effects on the detection capability of radar.

8.2.3 Output

The output of the SADRSPMWEE program includes the following plots:

(1) Minimum, mean, and maximum probabilities of single-scan detection versus range,

(2) Minimum, mean, and maximum probabilities of detection affirmation versus range,

(3) Signal-plus-clutter-to-noise ratio in dB versus range, and

(4) Signal-to-clutter-plus-noise ratio in dB versus range.

8.2.4 Future Works

Currently, SADRSPMWEE addresses environmental effects on radar detection, with the major emphasis placed upon the atmospheric refraction effect. SADRSPMWEE does not address radar mutual interference problems.

NWC considered SADRSPMWEE as preliminary in nature since work is continuing on the model development. Some areas of interest for the future extension of the model include the following;

(1) Diffraction curves for a bilinear ducting atmosphere,

(2) The calculation of the relativistic Doppler shift for a moving target,

(3) The calculation of attenuation due to eclipsing,

(4) Electronic countermeasure model,

(5) The calculation of the velocity of sound,

(6) Various weather effects, and

(7) Multiple targets model.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

This report presented a survey of existing radar system analysis techniques suitable for use in EMX design and performance evaluation of shipboard radar systems. Computer programs SEMCAM, PARDEG, SURSEM, and SADRSPMWEE were described. The efforts of ARC and ECAC in the development of signal processing circuit models and performance degradation models were discussed. Primary considerations were in analyzing the receiver processing effects on interference, the prediction of mutual radar interference, and the effect of mutual radar interference on performance capabilities. The major factors that affected the prediction of radar interference and radar performance were equipment, operator, and environments. Radar operator performance degradation, due to single and multiple interference, was studied. Pulsed interference was assumed in the analysis.

From this survey it appears feasible to develop a radar design algorithm and a radar performance evaluation algorithm. The radar design algorithm can be used as a design tool to predict potential radar interference when radar systems aboard a Naval ship are being designed. The radar performance evaluation algorithm can be used to evaluate radar performance degradation.

9.2 RECOMMENDATIONS

Currently available radar analysis algorithms, which appear to have the potential for providing the desired system analysis model, were evaluated. With this as background, this section recommends a new radar system analysis model as shown in figure 8.

The proposed radar system analysis model consists of two computer algorithms. The first is a design tool to be used by a design engineer during the process of designing shipboard radar systems. The second computer algorithm evaluates the radar system performance. It is intended to be used by the design engineer for the evaluation of his intermediate design and for the analysis of the radar performance under operational conditions.

In most cases, the algorithm for design will be used to determine, through iterative studies, the best possible use of available Navy equipment (within limits of the equipment characteristics and other constraints) as far as mutual radar interference is concerned. There are basically three steps in the process of designing a new shipboard radar system:

(1) The calculation of noise and interference power levels at the input to the victim receiver;

(2) The identification of any possible deficiencies in the design, by comparing the calculated value of the noise or interference level threshold criteria;

(3) Based on the results of the analysis described in the previous two steps, a design engineer can either find feasible solutions to improve the deficiencies, or can make trade-off decisions.

The computer algorithm for design will do the tasks described in the first two steps. The third step relies on the engineer's experience. Hopefully, the best possible use of available equipment can be reached through the iterative utilization of this computerized analysis algorithm and the engineering judgment of the design engineer. If new equipment must be used in order to meet the design goal of the system, the computer algorithm can be used to generate the required characteristics and specifications of the new equipment.

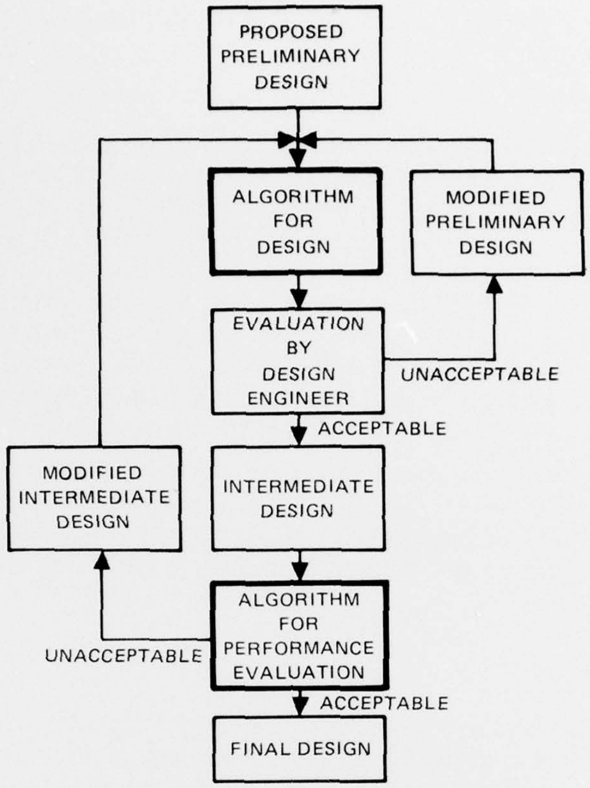

Figure 8. Proposed radar systems analysis model.

When an intermediate design is obtained, the second computer algorithm will be used to evaluate the performance of this design. Usually, this design is acceptable and will be the final design. In case it is not acceptable, the design should be modified.

Conceptually, these proposed radar design and performance evaluation algorithms are similar to DECAL (ref 1) and PECAL (ref 2) programs for the design and the performance evaluation of Naval shipboard communication systems. The concepts of DECAL and PECAL have been recognized as practical and useful ones. The proposed radar system analysis model will constitute a unified tool and technique that provides a design capability which relates a design to performance.

Currently, the function of initial target detection, when performed on Navy ships, is accomplished almost exclusively by radar operators viewing PPI displays. Future radars will use machine (automatic) detection and tracking systems. Therefore, the proposed radar design and performance algorithms should be applicable to human-PPI detection, as well as to automatic detection.

9.2.1 Proposed Radar Design Algorithm

The radar design algorithm will be a rapid and cost-effective radar system interaction analysis program. The program is envisioned which has the following features:

(1) The program is user-computer interactive and accessible from a time-share terminal of a main-frame digital computer.

(2) The program may consider both the best-case and the worst-case analyses just like SEMCAM does.

(3) The program considers the effect of single interference to a radar receiver. Pulsed interference is assumed.

(4) Each single interference can cause various interactions such as on-tune interference (burn-out), adjacent signal interference, spurious emission, spurious response, and broadband noise. The program considers these interactions one by one and identifies each interaction.

(5) The program includes signal processing circuit models like PARDEG does. The receiver processing effects on the interference are considered. Signal processing circuit models could be obtained from those developed by ARC and ECAC.

(6) The program sets some interference threshold criteria such as receiver noise (used in SEMCAM and PARDEG), zero dB/m for burn-out power level (used in SEMCAM and PARDEG), -105 dB/j for energy per scan for search radar (suggested by ECAC), a duty cycle of 0.05 for tracking radar (suggested by ECAC), displayed pulse count of 100 (suggested by ECAC), and external noise and clutters (required further studies). Each interference is compared with some interference threshold criteria. If an interference signal power level (or energy per scan, etc.) exceeds an interference threshold criterion, the existence of a mutual radar interference is predicted.

(7) The program has an external noise and clutter model to be used as an interference threshold criterion.

(8) The data base of the program can be obtained from those of the existing computer programs such as SEMCAM, PARDEG, SURSEM, and SADRSPMWEE, and from ECAC.

(9) State-of-the-art attenuation modeling and antenna coupling algorithms should be used. The algorithms may be run off-line, if necessary.

(10) The printouts of the program should indicate any possible deficiencies of the system and predict interference power levels at the input to the receiver, or at other points in the receiver.

9.2.2 Proposed Radar System Performance Evaluation Algorithm

The radar system performance evaluation algorithm is envisioned, which has the following features:

(1) The program is run in a batch mode.

(2) The program will use the Monte Carlo simulation technique, which is a statistical approach.

(3) The program considers the effect of multiple interference to a radar receiver. Pulsed interference is assumed.

(4) For each interference, the program considers various interactions as the radar design program does.

(5) The program considers signal processing circuit models as the radar design program does.

(6) The program calculates total performance degradation caused by all interference sources. The radar performance degradation may be expressed in terms of probability of detection, acquisition time, etc. The program considers both the effect of interference upon a radar operator utilizing PPI display, and radars with automatic (machine) detection and tracking systems.

(7) The program considers environmental effects on radar performance capabilities.

(8) A common data base may be shared by the design program and the performance evaluation program.

(9) The attenuation modelings and antenna coupling algorithms are the same as those of the design algorithm. Of necessity, these algorithms will probably run off-line.

(10) The printouts of the program should indicate radar system performance with and without interference, and predict individual interference source.

SEMCAM and PARDEG may provide an adequate analysis basis for the radar design algorithm. SURSEM and SADRSPMWEE may give initial information for the development of the radar performance evaluation algorithm. It may be possible to incorporate the signal processing circuit models developed by ARC and ECAC in the radar design and performance evaluation algorithms. Finally, SURSEM and SADRSPMWEE may provide a basic model to account for the effects of external noise and clutters.

10.0 REFERENCES

1. Rockway JW, Li ST, Baran DE, and Kowalyshyn W, Design Communication Algorithm (DECAL), paper presented at IEEE 1978 International Symposium on Electromagnetic Compatibility, in Atlanta, Georgia, 20–22 June 1978.

2. Minor LC, Koziuk FM, Rockway JW, and Li ST, PECAL – A New Computer Program for the EMC Performance Evaluation of Communication Systems in a Cosite Configuration, paper presented at IEEE 1978 International Symposium on Electromagnetic Compatibility, in Atlanta, Georgia, 20–22 June 1978.

3. Atlantic Research Corporation, NAVSEC SEMCA Computer Program User's Guide, prepared for Naval Ship Engineering Center, 29 May 1975.

4. Butturff HP, et al, Degradation to Search Radar PPI Reference in an Electromagnetic Environment, Atlantic Research Corporation, final engineering report 53-5588 prepared for Naval Ship Engineering Center, under contract no. N0024-73-C-1214, December 1974.

5. Atlantic Research Corporation, EM Degradation Feasibility Study, prepared for Naval Ship Engineering Center, under contract no. N00024-73-C-1214, August 1973.

6. Kaplan DJ, Grindlay A, and Davis L, Surveillance Radar Systems Evaluation Model (SURSEM) Handbook, NRL Report 8037, 14 January 1977.

7. Cornette WM, Search and Detection Radar System Performance Model with Environmental Effects: User's Manual and Program Listing, NWC Technical Memorandum 3150, April 1977.

8. Cornette WM, and Shlanta A, Radar System Performance Modeling with Environmental Effects (Preliminary Report), Volume 1, Theory, NWC Technical Memorandum 2698, Volume 1, February 1976.

9. NELC TD 506 (NOSC), Electromagnetic System Interaction Algorithms, ST Li, unclassified, January 1977.

10. Skolnik MI, ed, Radar Handbook, McGraw-Hill Book Company, New York, 1970.

11. Skolnik MI, Introduction to Radar Systems, McGraw-Hill Book Company, New York, 1962.

12. Atlantic Research Corporation, Search Radar PPI Performance Degradation from Multiple Interference prepared for NAVSEC under contract no. 75-C-7019, May 1976.

13. Atlantic Research Corporation, Tracking Radar (AN/SPG-51C) Performance Degradation in an EM Environment, prepared for NAVSEC.

14. Atlantic Research Corporation, Validation of PPI Detector Performance Degradation Model, prepared for NAVSEC, under contract no. 75-C-7019.

15. Moser PJ, Survey of Radar Analysis Techniques, ECAC report, 11 October 1977.

16. Lesniakowski T, Special Circuits Survey, ECAC, ECAC-HDBK-77-23, February 1977.

17. Aasen M, Methods for Predicting the Effects of Interference on Tracking Radar, ECAC, ECAC-TR-63-2, August 1962.

18. Showalter GL, F-14A-/AWG-9 Radar/Task Force Environment EMC Analysis, ECAC, ESD-TR-71-095, June 1971.

19. Box F, Cuthbertson J, Newhouse P, and Schwartz L, Tactical Electromagnetic Environment Evaluation Model (TEEM); Phase II, ECAC, ECAC-PR-73-031, July 1973.

20. Baker A, Cuthbertson J, Krueger R, An EMC Analysis of the AN/TPS-37 Radar System, Volume 1, ECAC, ECAC-PR-74-049, January 1975.

21. Katz L, PPI Interference Prediction IEEE Trans. on Electromagnetic Compatibility, June 1965.

22. Lustgarten MN, An Approach to the Radar Operational Degradation Problem, ECAC, ECAC-TN-71-34, July 1971.

23. Lipman P, and Lustgarten M, Survey of Literature on Radar Operational Degradation, ECAC, ECAC-TN-73-15, July 1973.

24. Hudson EL, Search Radar Performance Degradation, RADC-TR-65-539, May 1966.

25. Bailey HH, Target Detection Through Visual Recognition: A Quantitative Model, Rand Corporation RM-6158-PR, February 1970.

26. Lustgarten MN, and Grigg RD, Effects of Radar Interference on Search Radar Operator Performance, paper presented at 1977 IEEE International Symposium on Electromagnetic Compatibility, in Seattle, Washington, 2–4 August 1977.

27. Pierstorff BC, Rosentahl P, and Hanes CM, Simulation of Radar/Radar Interference at RF for the Evaluation of Interference Effects on Operator Performance, paper presented at IEEE 1977 International Symposium on Electromagnetic Compatibility, in Seattle, Washington, 2–4 August 1977.

28. Marcum JI, and Swerling P, Studies of Target Detection by Pulsed Radar, IRE Trans. IT-6, No. 2 (1960).

29. Davis LC, and Trunk GV, Surveillance Radar Detection (SURDET) Program, NRL Report 8228, 11 August 1978.

30. Wilson JD, A Multiple-Radar Integrated Tracking (MERIT) Program, NRL Report 8200, 3 April 1978.

INITIAL DISTRIBUTION

NAVAL ELECTRONIC SYSTEMS COMMAND
CODE 3041 (J. A. CAUFFMAN) (3)
CODE 51034 (R. PRIDE) (2)
CODE 5103 (DON WILSON)
CODE 5102 (C. NEILL)
NELEX-095 (M. RONEY)

NAVAL SHIP ENGINEERING CENTER
NSEC-6174F (P. LAW)
NSEC-6174D (F. PROUT)
NSEC-6174E (J. ROMAN)

CHIEF OF NAVAL MATERIAL
NMAT-034 (M. NUNN)

NAVAL SEA SYSTEMS COMMAND
NSEA-06T (J. MC EACHEN)
NSEA-034 (H. J. DE MATTIA)

NAVAL RESEARCH LABORATORY
CODE 5308 (DR. GERARD V. TRUNK)

NAVAL AIR SYSTEMS COMMAND
NAIR-360A (F. J. LUEKING)

NAVAL WEAPONS CENTER
CODE 3173 (DR. ALEXIS SHLANTA)
CODE 3313 (G. RYNO)

ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER
J. HODGES (3)

ROME AIR DEVELOPMENT CENTER
GRIFFIS AFB, NY 13441
RBCT (JAMES C. BRODOCK)
RBCT (GERARD T. CAPRARO)

NAVAL POSTGRADUATE SCHOOL
DR. R. ADLER

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE LABORATORY
P. O. BOX 808
LIVERMORE, CA 94550
L-156 (DR. A. POGGIO)

GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
ATLANTA, GA 30332
DR. STEPHEN N. COLE

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
JOHNS HOPKINS ROAD
LAUREL, MD 20810
ARTHUR WILLIAMSON

OHIO STATE UNIVERSITY
COLUMBUS, OH 43212
DR. C. WALTER

ATLANTA RESEARCH CORPORATION
ALEXANDRIA, VA 22314
TOM SAUTER

BOEING COMPANY
P. O. BOX 3999
SEATTLE, WA 98124
MS 8C-52 (DR. W. COOLEY)

DEFENSE DOCUMENTATION CENTER (12)